July 1, 2004 to June 30, 2005

Annual Performance Report

CICAR
Cooperative Institute for
Climate Applications and Research

LAMONT-DOHERTY
EARTH OBSERVATORY
THE EARTH INSTITUTE AT COLUMBIA UNIVERSITY

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COOPERATIVE INSTITUTE FOR CLIMATE APPLICATIONS AND RESEARCH
THE EARTH INSTITUTE AT COLUMBIA UNIVERSITY

2005 Annual Report to NOAA

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Preface

Document Purpose:

The Annual Report for the Cooperative Institute for Climate Applications and Research (CICAR), a Cooperative Institute funded by the National Oceanic and Atmospheric Administration Office of Oceanic and Atmospheric Research (OAR), is a requirement of the OAR Cooperative Institute Program. The CICAR annual report describes all actively funded research projects, education initiatives, and public information and outreach programs conducted under CICAR NOAA grant NA03OAR4320179 for the fiscal year ended June 30, 2005.

Looking forward to FY 06 the CICAR annual report presents a window to future research activity as well as CICAR's administrative and public outreach program development. As a contributor to the OAR Cooperative Institute Program, CICAR research will, on a yearly basis, actively address NOAA's Strategic Goal to *Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond*.

Document Distribution:

The CICAR Annual Report is distributed in hard and soft copy to the NOAA/OAR Cooperative Institute Program Office and is available in PDF version on both the OAR CI web site and the CICAR web site (http://www.ldeo.columbia.edu/cicar/index.html). Copies of the report will be made available to the members of the Columbia University, Earth Institute, and Lamont-Doherty administrative and scientific communities as well as other interested agencies and individuals.

Document Contents:

The 2005 CICAR Annual Report is a comprehensive written review of all administrative and research activity for the Institute's second year of operation that began July 1, 2004 and ended June 30, 2005.

About CICAR

Mission Statement:

The Cooperative Institute for Climate Applications and Research evaluates, understands, and predicts climate variability and change through the collection and analysis of modern and paleoclimate data and the use of Earth system models. We provide climate information to society through education and the development of applications and tools for assessing climate-related risks.

CICAR's research is directly aligned with NOAA's mission goal to *Understand climate variability and change to enhance society's ability to plan and respond.*

Overview:

The Cooperative Institute for Climate Applications and Research (CICAR) was established in November 2003 as a research partnership between the National Oceanic and Atmospheric Administration and Columbia University In The City of New York. CICAR research themes are: (1) Earth System Modeling; (2) Modern and Paleoclimate Observations; and (3) Climate Variability and Change Applications Research.

The NOAA funded research portfolio at Lamont grew out of a clear strategic vision of scientists at LDEO and NOAA. This vision stipulated that ocean observations and coupled ocean-atmosphere modeling are key to understanding long-term climate variability and change and to developing climate prediction capabilities. It also emphasized paleoclimate research as providing climate scenarios quite unlike those revealed in the short instrumental record, thus helping to expand our view of the Earth climate system and challenging our conceptual understanding and modeling capability. Actively pursuing these ideas LDEO scientists worked with NOAA to form programs and set research directions.

At the core of the CICAR research agenda is the collaboration between LDEO and two NOAA climate-oriented organizations: the Office of Global Programs (OGP) and the Geophysical Fluid Dynamics Laboratory (GFDL). OGP leads the NOAA involvement in the U.S. Climate and Global Change (C&GC) Program and sponsors scientific research aimed at understanding climate variability and its predictability. GFDL is "charged with producing timely and reliable knowledge and assessments on natural climate variability and anthropogenic change" through the development of Earth system models and theoretical understanding. Both these missions are consistent with the CICAR climate research agenda.

Structure:

CICAR is administered by Columbia University through its Lamont-Doherty Earth Observatory and is located at the Observatory's Palisades, New York campus. The Institute consists of the Director, who is an official of Columbia University, an administrative staff, an Advisory Committee, an Executive Board to be convened for the first time in September 2005, and the scientific and support staff of the CICAR and members of LDEO and other units of the Earth Institute at Columbia University. The Geophysical Fluid Dynamics Laboratory, a NOAA Research facility, is the Institute's principal connection to NOAA.

Research Overview:

The Cooperative Institute for Climate Applications and Research develops and promotes research to address a wide range of science and social topics consistent with the CICAR mandate. The project overviews appearing in the research section include: observations and model development required for the prediction of seasonal-to-interannual and long-

term climate variability; collecting instrumental observations and developing and archiving proxy records for deepening the understanding of climate variability and change; and for the development of tools for providing climate information to society to assess risk and make decisions.

The CICAR program of research and education strives to:

- Create a long-term research partnership between NOAA and the Columbia University climate research community to enhance NOAA's research capabilities in the area of climate observations, modeling, and prediction.
- Contribute to NOAA's goal to enhance society's ability to plan and respond to climate variability and change by developing methods and tools for providing climate information to users and decision makers.
- Provide a basis for streamlining the administrative process for several established cooperative projects within Columbia University and NOAA – e.g. Abrupt Climate Change Studies (ARCHES), Climate Variability and Prediction program (CLIVAR), the IRI Applied Research Centers program, and the NOAA Economics and Social Science program.
- Develop specific research projects that address critical research needs in:
    - Climate modeling and prediction
    - Modern and Paleoclimate research
    - Climate forecast applications research
- Create undergraduate-to-graduate level research and education opportunities that reflect NOAA priorities and interest through student participation in related science projects and by bringing NOAA science perspectives into the classroom.
- Identify opportunities and establish means to communicate climate research development to the public to facilitate broader understanding of climate related issues and their impact on society.

Research projects (and related education activities) under CICAR address three overarching themes:

Theme I: Earth System Modeling

- Developing and improving climate models and modeling tools (e.g., data assimilation procedures) to simulate and predict climate variability and change.
- Designing of climate experiments with numerical models of varying complexity to test hypotheses and promote understanding of climate variability and change.
- Applying statistical tools to data and model output to study modes of climate variability and their predictability.
- Analyzing historical data to create spatially and temporally uniform information for research and applications.

Theme II: Modern and Paleoclimate Observations

- Developing, collecting, analyzing, archiving, and interpreting paleoclimate data records to improve understanding of climate variability and change on all time scales.
- Monitoring and observing the key ocean regions to understand the ocean role in climate and to improve climate models.

Theme III: Climate Variability and Change Applications Research

- Developing applications and tools that enable the translation of climate information to decision makers in the areas of agriculture, water resources, health, economics, and policy.
- Studying the interaction between providers of climate information and users and decision makers to improve communication for the benefit of society.

Operational Strategy by Task:

The Institutes primary operational and research strategy is divided into four (4) tasks:

Task I: Administrative activities
Task II: Specialized science support activities
Task III: Proposed and currently funded individual projects
Task IV: Collaborative education program

Forward

Budget year 2004-2005 marks CICAR's second year of operation. Notable this year is the folding of all the NOAA funded, individual PI projects at Columbia University (primarily at LDEO) under the umbrella of the five-year Cooperative Agreement. This is reflected in the significant increase in the number of projects reported on below. From the administrative point of view, this achievement reflects the successful adjustment of the Columbia University and LDEO Offices of Projects and Grants to the new funding structure dictated by the Agreement.

This has been a good year for CICAR with a push towards new projects and the fruition of old ones. Among the most gratifying aspects of the research this year is the commencement of a genuine collaboration between LDEO and GFDL scientists under the GFDL funded effort to model the climate of the last 1000 years. The NOAA Office of Global Programs has continued to provide the major bulk of funding for our research projects sponsoring work on climate prediction, climate modeling, and modern and paleoclimate data collection and analysis.

In the last month of this budget year, amidst our achievements and feelings of accomplishment, came the sad news on the passing away of Gerard Clark Bond, one of Lamont's most original and prolific scientists. A world-renowned scientist, Gerard played a pivotal role in the NOAA funded ARCHES project and his contribution to mapping and understanding abrupt climate change during the last glacial and the Holocene will be greatly missed.

We have now started a new budget year looking forward to expanding the Institute's research portfolio. Our scientists responded enthusiastically to the last call for proposals from the Office of Global Programs. During the summer we established the CICAR Executive Board, which includes administrators and scientists from NOAA and Columbia University and which will convene for the first time at the end of September. We will also mark the end of the second year of CICAR by a joint symposium with GFDL to address the challenge of modeling the climate of the last millennium – the theme of our collaboration effort. As our scientific research diversifies and develops to address the NOAA goals we will also work to strengthen and expand our education and outreach activities.

Executive Summary & Research Highlights

The CICAR 2005 Annual Report is a summary of the administrative, educational, and research activities performed during the second year of our cooperative agreement with NOAA. During budget year 2004-05 the bulk of NOAA funded research projects at Columbia University were brought under the CICAR agreement[1]. With the addition of new funding, CICAR is now boasting 23-funded research and education projects in addition to its core administrative budget. This report gives a detailed, project-by-project accounting and includes summary tables and graphs designed to reflect the cumulative scientific and administrative activities of the Institute.

The present CICAR research portfolio brings the broad expertise at LDEO to bear directly on the NOAA mission to serve the public need for climate information and prediction. It helps create critical assessment of the variability in the recent climate record and the projections of future climate changes provided by climate models, by putting them in context of a much broader picture. Within this framework the collaboration between LDEO and the NOAA Geophysical Fluid Dynamics Laboratory (GFDL) in Princeton, NJ clearly benefits both NOAA and Columbia University.

As explained above (see "About CICAR", page ii) each research project and related education activities under CICAR address one or more of three overarching themes: (I) Earth system modeling; (II) Modern and paleoclimate observations; and (III) Climate variability and change applications research. In its second budget year CICAR featured eight projects under theme I, fourteen projects under theme II, and one project under theme III.

The various activities under CICAR can also be grouped along the lines of their underlying research agenda and we summarized the highlights according to this criterion.

1. **Abrupt Climate Change Studies (ARCHES)** project, funded by NOAA OGP under the Consortium on the Ocean's Role in Climate (CORC). It currently includes a collection of 12 different project (see Table 1, page 100). Together these projects represent a comprehensive collaborative effort to "describe, understand and assess the likelihood of abrupt changes in the climate system, and to identify the mechanisms involved" (see http://www.ldeo.columbia.edu/res/div/ocp/CORC-ARCHES/). The unique aspect of this effort, which began in 1998, is that it combines paleoclimate research with modern ocean observations and numerical modeling to search for the pattern, cause, and process of past abrupt climate change and evaluate the odds for such events in the future. The project is now entering its synthesis stage and is slated to produce a comprehensive review of past research. Highlights of ARCHES research include:

   Paleoclimate research:

   - Making headway in studying abrupt climate change in the Southern Ocean during the last glacial period – identifying new proxies and detecting changes. Result show evidence for local abrupt changes (not linked to Northern Hemisphere ones) as well as the first evidence for Southern Ocean remote response to Heinrich Events.
   - Unique use of isotopes of the rare earth element neodymium (Nd) as a proxy yields a high-resolution picture of the deep Atlantic circulation during the past 90,000 years. The study provides new evidence that ocean circulation changes lagged behind and were not the cause of major climate changes at the beginning and end of the last ice age.
   - Compilation of proxy data from deep sediment cores shows that the Agulhas leakage into the Atlantic existed during last glacial maximum (LGM), much like in modern times, but that its retroflection was located further north of the present position.

[1] This does not include the funding for the International Research Institute for Climate Prediction (IRI), which is managed under a separate cooperative agreement.

- Consolidating previous results on changes in the equatorial Pacific during the LGM: evidence of weakening in the equatorial front, a southward shift in the ITCZ, and a colder cold tongue (~2° cooler than the present). Our results provide unambiguous view of the glacial-inerglacial pattern of change in the Pacific cold tongue-ITCZ front, as a part of the global dynamical adjustment of the ocean and atmosphere during the glacial cycles.
- Continued detailed mapping and dating of LGM glacial moraines of the Southern Hemisphere, particularly New Zealand, and relating these to Northern Hemisphere abrupt change events.
- Finding evidence for reworked material in planktic foraminifera shells that affects radiocarbon dating in sediment core. This has important ramifications for verifying dates in these records.
- High-resolution Holocene records of Mg-Ca ratio from North Atlantic cores yields evidence for 1-1.5°C changes in surface temperature during rapid climatic fluctuations. These results confirm earlier evidence, derived from petrologic indices, on considerable changes in surface conditions.
- The moderate cooling of the climate in the high northern latitudes of the North Atlantic in the last 4000 years, most likely forced by orbital changes, has lead to enhanced convection and increased meridional overturning.

Modern observations:

- Agulhas leakage plays an important role in moving dense surface water from the Southern Ocean into the Atlantic to promote meridional overturning there. A large proportion of Agulhas flow contains Indonesian throughflow water.
- Recently recovered Weddell Sea moorings provide an almost six-years long time series and record changes in Antarctic Deep Water formation rates. These records span the breakup of the Larsen B ice shelf in early 2002. A detailed study of these results is underway.
- Quantifing ocean sensible heat flux to the West Antarctic Peninsula and finding a large jump in heat content of the shelf water there in the recent decade and a half.
- Deep outflow moorings from Western Weddell Sea were reached for the first time in three years and tracer samples were recovered to allow calculation of the rate of formation melt water under the Ross Ice Shelf (0.85 Sv) and their residence time beneath the shelf (3.5 years).
- Compiling maps linking global helium isotope distribution to Southern Ocean ventilation rates.

Climate modeling:

- Conducted modeling work to investigate the rearrangement of the climate system in response to changes in tropical Pacific SST and the related impact on the global hydrological cycle. Effects on the zonally averaged circulation as well as on regional climate such as North America and the North Atlantic were studied. Particular attention was given to the role of the tropical Pacific in forcing drought conditions over the US Great Plains and Southwest.
- Results from a suite of coupled and uncoupled model ensembles show clear evidence to the primary role played by decadal and longer-term changes in tropical Pacific SST in inducing either drought conditions or their opposite (wet conditions) for extended periods of time. We compare model results to observations and to proxies of soil moisture derived from tree-ring chronologies.

2. **Climate of the Last Millennium**: A recently established project, funded by GFDL to support modeling and analysis work on global and regional climate variability and change during the last 1000 years. The project emphasizes collaboration and joint project planning, between LDEO and

GFDL. A number of senior Lamont and GFDL scientists are involved in this work, at no-cost, providing joint mentorship to graduate students and postdoctoral research scientists. The project is designed to put the simulations of the climate of the 20 Century (with the GFDL and other models) and of future, greenhouse-gas-forced climate change, in perspective of the variations in climate from the Medieval Warm Period through the Little Ice Age and into the present, through the examination of phenomena and mechanisms associated with regional and global variability. The project research highlights are:

- An objective algorithm to detect "sudden stratospheric warming" was designed and is used to study the dynamics of such events in GFDL model simulations.
- GFDL model runs designed to study water vapor transport and the source of dry subtropical air exposes the important role played by extratropical transients and the secondary role of the Hadley circulation.
- A "matrix transport" method for fast simulations of biogeochemical tracers in ocean models was implemented in the GFDL model.
- Developed a user-friendly, web-based access to the GFDL data portal, which enables LDEO scientists access to up-to-date simulations with the GFDL models.

3. **Other projects addressing CICAR Theme I: Earth System Modeling**

Funded mainly by NOAA OGP under their various programs. This research is driven by individual PIs, frequently in response to OGP announcements of funding opportunities. Major findings in this category are listed below:

- Begin using a new version of the LDEO intermediate coupled model (alias LDEO5) for ENSO operational prediction (the model adopts a new procedure of bias-corrected, forecast initialization making use of SST data)
- Use LDEO5 to study the predictability of tropical Pacific SST on decadal time scales to show that the model does predict the change in the probability distribution of the so-called "Pacific climate shifts". The model was also used to study epochal dependence in ENSO predictability and the impact of forcing, external to the tropical Pacific, on ENSO variability.
- Sensitivity experiments with the Lamont Ocean Model (LOAM) show that interannual variability of precipitation has a significant impact on upper ocean dynamics in the tropics. Given that the uncertainty in available precipitation products can be as large as their interannual variability, there is considerable uncertainly in the resulting model response.
- Numerical investigation of mechanisms maintaining the summertime low-level jet over North America's Great Plains demonstrates the important role played by topography. Consistently, the skill in simulating summertime rainfall is increased when downscaling the GCM results by using regional models.
- Diagnostic studies of more than a century of SST data shows that interannual variability of the tropical Atlantic interhemispheric SST gradient – an important factor in rainfall variability over N.E. Brazil – is more often consistent with the remote response to ENSO than with other, local influences. However, the ENSO influence is not dominant enough to ignore the latter. Of particular interest is the role of SST variations in the South Atlantic and their predictability. These are now studied using a coupled GCM.

4. **Other projects addressing CICAR Theme II: Modern and Paleo Observations**

As in section 3 above, these are also funded by NOAA OGP. Major findings in this category are listed below:

- Continued work on the North American drought reconstruction grid to develop and add a continually updated, new instrumental dataset to the tree-ring based one. Expanded the geographical coverage of the reconstruction based tree-ring data into Alaska and Canada based in total on 1147 chronologies.

- Successfully designed, deployed, and tested an autonomous, remotely accessible system to measure pCO_2 concentrations, for SABSOON. The system output, combined with data from synoptic trajectory models allows the study of the origin of coastal CO_2 signals.
- Assembly of a high-end meteorological sensor suite for incorporation in the integrated observing platform SOLAS and preparing for testing the platform during the fall of 2005.

5. **M.A. Program in Climate and Society**: Last year, Columbia University established a new graduate program to train professionals and academics to "understand and cope with the impact of climate variability and change on society and the environment." The NOAA Office of Global Programs participated in tuition support to some of the program participants. This M.A. program builds into the CICAR portfolio an element that falls under the stated Theme III and at the same time addresses the education mission of the Institute.

   The interdisciplinary curriculum offered by this program is unique, as is the diverse background of the participating students. In all, 18 students graduated from this program and will receive their degree in October 2005. The graduating students have been successful in finding internships and job placement at prestigious national and international institutions prominent in the filed of climate and society interactions.

Looking Forward

At present, we are set to host the first CICAR sponsored scientific meeting – a Symposium on the Climate of the Last Millennium – and to convene the first meeting of the CICAR Executive Board, with representatives from the University and NOAA. Looking back at last budget year, we are inspired by the array of accomplishments and are set for the challenges of expanding CICAR's role within the Cooperative Institute community and the NOAA research agenda. We expect to achieve more balance in the division of projects between themes and to increase our education and outreach activities.

CICAR Tasks

Task I: Administrative

Addresses the administrative functions of the Institute and supports the CICAR director and one (1) administrative staff member:

Administrative Staff:

CICAR Director

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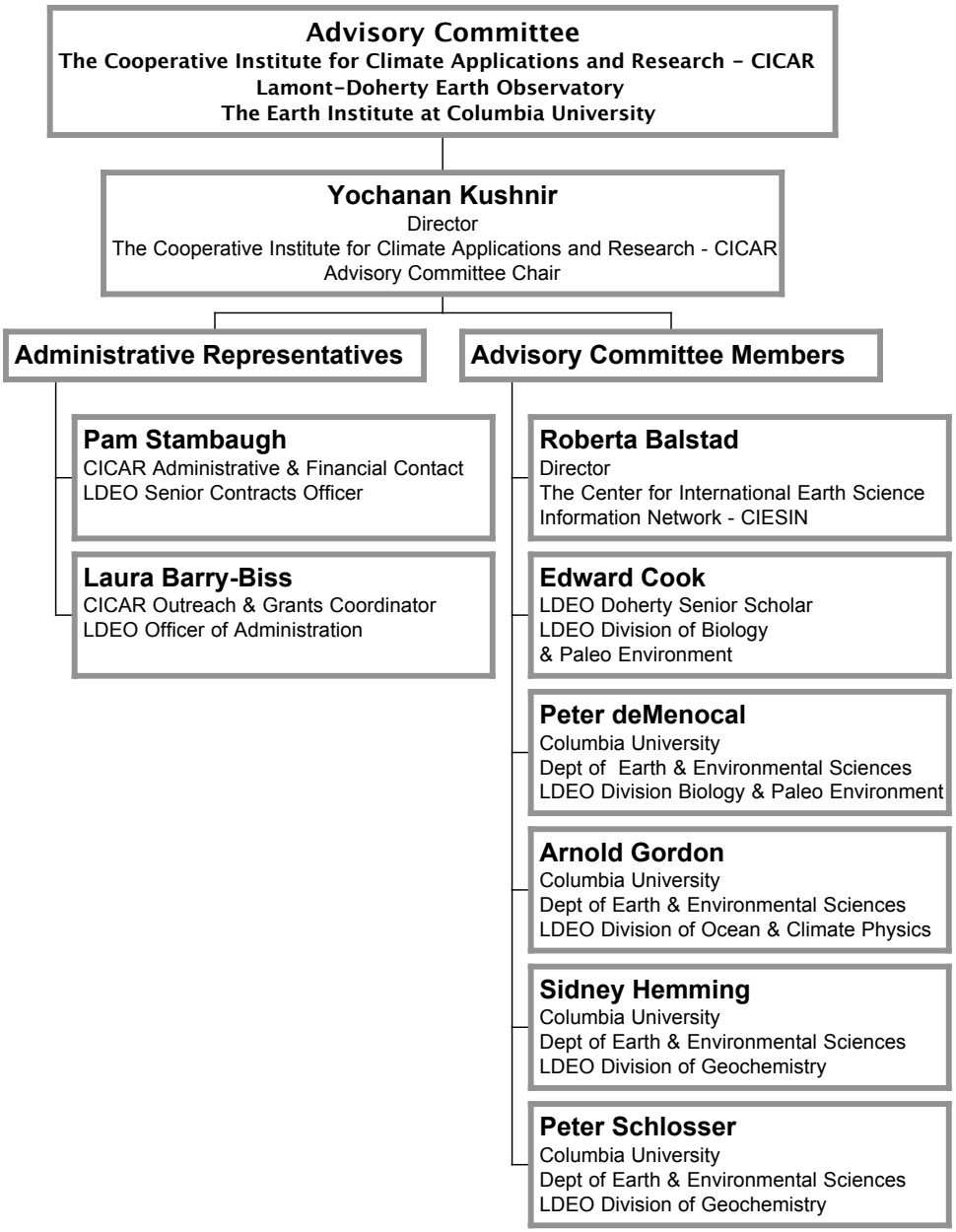
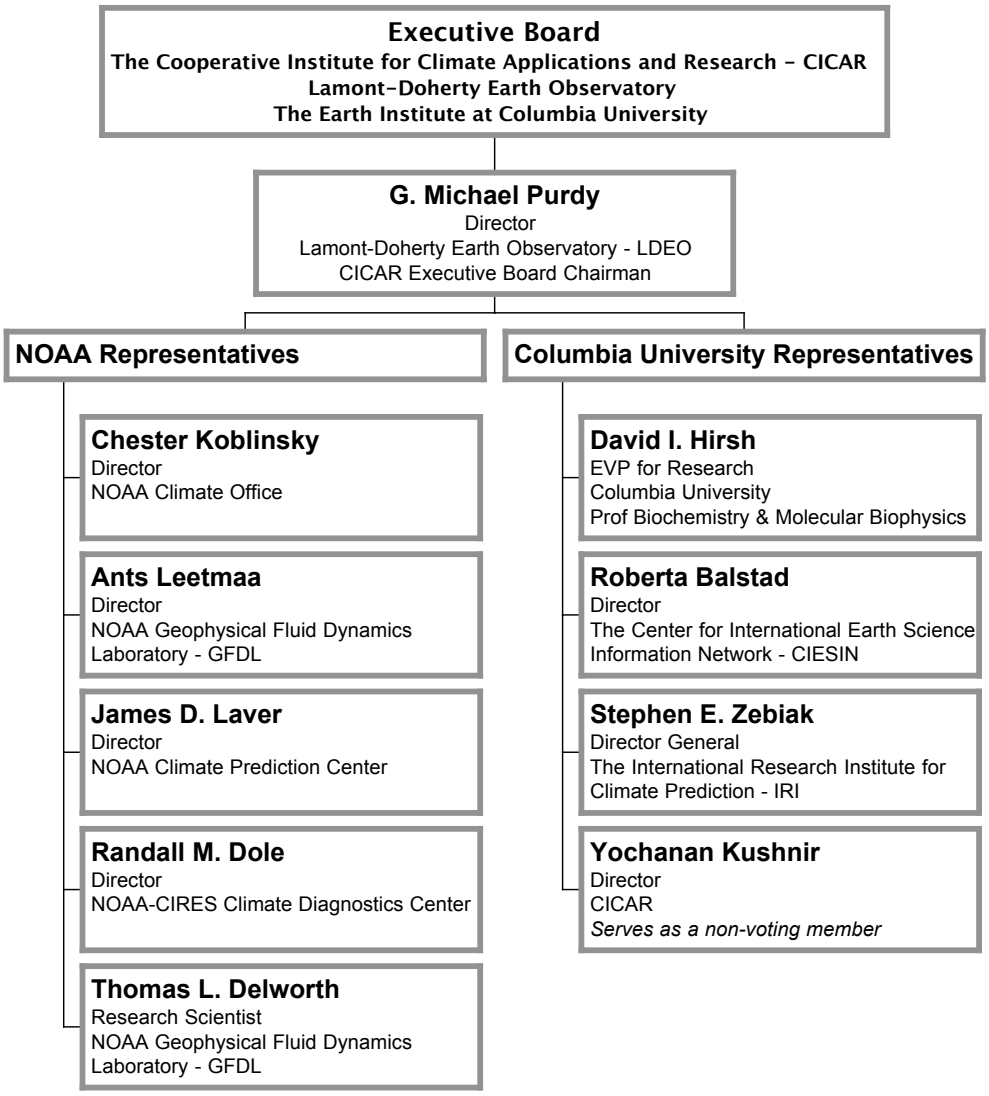
CICAR Advisory Committee and Organization Chart:

The CICAR Advisory Committee includes representation from the Institute's director and deputy director, the administrative staff, and senior scientists representing various Columbia University research divisions and affiliates. Committee meetings are convened at the discretion of the Director and address areas of scientific leadership, research coordination, strategic planning, and priority setting. The group's collective knowledge is a valuable resource for the Director in his decision-making responsibilities.



CICAR Executive Board and Organization Chart:

The CICAR Executive Board will meet for the first time on September 29, 2005 at the Lamont-Doherty Earth Observatory in Palisades, NY. Board members are charged with *invigorating the Institute's commitment to new and existing scientific program areas and counseling the CICAR Director on matters of policy, budget, and ways to improve coordination of research programs with other institutions or agencies.*



CICAR Administrative Activities July 1, 2004 – June 30, 2005

Education and Community Outreach

Sponsored Seminars

As part of the LDEO Ocean and Climate Physics Seminar Series these scholarly talks give Lamont scientists an opportunity to learn more about their colleagues' research and to interact with these visiting scientists in an informal setting.

- January 28, 2005 - Brian Arbic, GFDL/Princeton University: *Ocean Tides and Heinrich Events*
- March 11, 2005 – Kerry Emanuel, MIT: *Tropical Cyclones and Climate Change*

Web Site

- Debuted November 1, 2004 http://www.ldeo.columbia.edu/cicar/index.html
- Created and maintained by LDEO Web Services and CICAR Administration
- Established web links with internal and external partners including various NOAA.gov sites

Promotional Material

- CICAR brochure
  - Content development by CICAR Administration
  - Creative development and editing supervised by Mark Inglis, Creative Director for the Earth Institute at Columbia University, at no cost to CICAR

External and Hosted Activities:

Lamont-Doherty Earth Observatory – Open House Saturday, October 9, 2004:

Thousands of visitors attended last year's event, many of who visited the CICAR display. Institute representatives spoke with students, educators, and the general public about such timely issues as Global Warming and Abrupt Climate Change. Teachers especially were eager to find new and creative ways to introduce their students to these important environmental challenges.

With the enthusiastic support of OAR's Linda McLaughlin and Alice Gottschling, hundreds of NOAA posters and brochures were available to the public and were instrumental in delivering NOAA's message "to better observe and understand the climate system, improve forecasts and allow society to better respond and adapt to climate variability and change." CICAR Administration produced posters that dealt with energy conservation and NOAA Goals and Priorities for use by teachers and students. The posters were available in hard copy and electronic format enabling educators to reproduce them for a wider audience.

Attracted by the dynamic images of nature's fury, students showed particular interest in the NOAA **SEVERE WEATHER** poster.

Advisory Committee Meetings:
September 29, 2005 agenda items:

- Distributed and reviewed the CICAR 2004 Annual Report
- Discussed CICAR year 1 progress, future goals, and governance issues including the formation of an Executive Board
- Introduced the Federal grant opportunity and application web sites – grants.gov and grantsonline.gov
- Discussed the NOAA 2005 budget and continuation funding for Abrupt Climate Change and Paleoclimate research
- Discussed the proposed restructuring of NOAA Research and its implications for ARCHES research
- Previewed CICAR web site

March 17, 2005 agenda items:

- Presented the "Proposed NOAA Policy and Process for Creating and Managing CIs" document
- Discussed project funding status including *FY 2006 President's Request* and grants administration procedures and online submission
- Discussed education activities – postdocs and students, Earth Science intern, and LDEO Ocean and Climate Physics seminar series sponsorships
- Reported to the committee on the NOAA/CI Directors and Administrators meeting, Silver Spring, MD March 9 – 10, 2005

March 9 - 11, 2005: NOAA OAR JI Directors and Administrators Meeting in Silver Spring, MD.
The CICAR contingent found the meetings extremely informative and agreed to the need for both groups to meet annually.

CICAR Symposium scheduled for September 28, 2005 at the Lamont-Doherty Earth Observatory, Palisades, NY

- *The Climate of the Last Millennium*
- Spotlight University research under CICAR and the collaboration with GFDL
- Speakers include: Wally Broecker, Lloyd Kweigwin, Erica Hendy, Ed Cook, David Stahle, David Rind, Ruth Curry, Rong Zhang, Gabriel Lau, Julien Emile-Geay, Michela Biasutti, and Richard Seager

CICAR Executive Board meeting scheduled for September 29, 2005 at the Lamont-Doherty Earth Observatory, Palisades, NY
Michael Purdy, Observatory Director, will chair the first meeting of the CICAR Executive Board. Board members will be asked to consider matters of science and policy and to develop strategies for growing the Institute.

Task II: Specialized Science Support Activities

This task provides for specialized support scientists that are employed by Columbia University (LDEO) but are located at the Geophysical Fluid Dynamics Laboratory (GFDL). These CICAR employees are hired to enhance the technical and scientific expertise at GFDL required to execute collaborative CICAR projects or to address specific needs that require specific expertise not available at GFDL. In the present 5-year budget cycle we propose to allow for five such support scientist positions. It should be noted that, to date, these slots have not been filled.

Task III: Individual & Collaborative PI Research Projects

This task encompasses the bulk of individual and collaborative PI research at LDEO / EI that is supported by grants from NOAA and complies with the themes of CICAR. It is comprised of currently funded research projects as well as new ones that strengthen the Institute research agenda in line with the themes. Task III represents the main thrust of the CICAR research agenda for the next two years.

Theme I: Earth System Modeling

Project Title: **ARCHES: Abrupt Climate Change: Modeling Scope**

Principal Investigator: Richard Seager
Affiliation: Lamont-Doherty Earth Observatory

NOAA Program Manager: Dr. James Todd, CLIVAR Atlantic NOAA/OGP, 301-427-2089 Ext. 2383, james.todd@noaa.gov

Research Goals:

To understand the causes and mechanisms of abrupt climate changes in the past using numerical models of the atmosphere and ocean.

Education Goals:

We aim to actively involve undergraduates and graduate students in the research as well as to disseminate results broadly to facilitate public education and better understanding of climate dynamics.

Research Progress:

In this year we have advanced the idea that abrupt climate changes during glacial periods (Dansgaard/Oeschger events) were caused by abrupt changes in the global coupled atmosphere-ocean circulations. It is considered that these were instigated within the tropics and involved changes in the jet stream/storm track regime over the North Atlantic Ocean. Climate modeling has shown how the atmosphere and ocean circulations over the North Atlantic are coupled in a way that involves a substantial positive feedback with a northerly drift of the jet stream/storm track forcing poleward ocean flow, warming the subpolar North Atlantic Ocean which in turn induces an atmospheric response with a northward tilted jet stream/storm track. Other modeling has shown the potential for a tropical climate rearrangement to cause a shift from this regime into an alternate regime with a zonal atmosphere-ocean circulation and a vastly colder North Atlantic. Modeling work is underway to examine the feasibility of this regime changes as a cause of glacial period abrupt change.

Other work has examined the causes and dynamics of persistent extratropical precipitation anomalies such as the Dust Bowl drought of the 1930s and other severe hydroclimatic events that, by many standards, begin and end abruptly. Using analyses of long tree ring records, instrumental records and climate models we have demonstrated that these are forced from the tropical Pacific and are contained within patterns of climate change and variability that have obvious zonal and hemispheric symmetry. The results are of relevance to abrupt changes in the more distant past in that the identified mechanism – a subtropical jet-transient eddy-mean meridional circulation interaction mechanism – can create synchronous and in phase climate change in the extratropics of each hemisphere. The global footprint of climatic and hydroclimatic can be, and will be, contrasted with that deduced from proxy data.

The tropical warm pools play an important part in determining the mean climate of the planet and, potentially, in climate change. We have presented a study of how they come into existence. A warm pool can be created as a consequence of trade winds, Sverdrup dynamics in the ocean and Ekman flow in a shallow mixed layer. As such the warm pools are a consequence of coupled dynamics. The warm pool becomes more meridionally confined as the thermocline deepens. A deeper thermocline also means that ocean heat transport is reduced, and atmosphere heat transport increases. According to many climate models, that shift in partitioning of heat transports causes a cooling of the planet as low cloud cover increases and subtropical humidity decreases. Since the mean thermocline depth is tied into the global ocean heat budget, as well as the overturning circulations, this suggests that there are means whereby atmosphere and ocean circulations, globally, can change, induce the tropical thermocline to deepen and cool the planet. Our work on coupling between tropical ocean and atmosphere heat transports suggests that there is a strong negative, stabilizing, feedback between them. In contrast we have been able to show that extratropical climate changes could, potentially, influence tropical thermocline depths and ocean heat transports.

We have also examined future climate change in seven Coupled Model Intercomparison Project Phase examining the greenhouse gas impact on stationary waves and regional climate. During winter over the US, both precipitation and surface temperature changes are influenced by the so-called Pacific North American (PNA) pattern. When the models show a positive PNA response to greenhouse warming, there is increased precipitation over the US northwest associated with the extended Pacific jet and the associated storm track. During summer, most models show a drying tendency over most of the US, particularly over the southern part of the country, indicating increased threat of drought. The Great Plains Low Level Jet is an important supplier of moisture to North America during summer. Modeling experiments have been conducted to examine the dynamical origins of the jet as a means to understanding how it can change.

Recent trends in satellite observed tropical mean top-of-atmosphere radiative fluxes are not captured in climate models forced by observed SSTs. Work in the last year indicates that both circulation changes and cloud microphysical processes could alter the top-of-atmosphere radiation budget, and that these processes could explain the discrepancy between the observations and climate models. In particular, a large feedback between circulation and low clouds was identified in the GFDL atmospheric model. This is a potentially large feedback also of relevance to past climate change that motivates further study of the relationship between circulation and boundary layer clouds.

Highlights:

- Proposed global atmosphere-ocean coupling concept of abrupt climate change
- Determined mechanisms of generation of global hydroclimate regimes
- Proposed mechanism for generation of tropical warm pools and mechanisms for changes in their extent.
- Examined potential for greenhouse-gas induced changes in atmosphere circulation to increase drought threat in mid-latitudes

Societal Benefits:

The work is of direct societal benefit in that it is leading to a better understanding of the causes and mechanisms of dramatic changes in global hydroclimate, including the recent (1998-2004) severe drought in the American West. This work has attracted significant attention amonst the wider scientific community and the public. The work is also of relevance in that increased understanding of regimes of atmosphere-ocean circulation will lead to a better idea of how anthropogenic forcing will impact global and regional climate.

CICAR / NOAA Funded Research Connections:

Interagency:

The work allowed us to successfully seek funding from NSF to specifically study the last millennium of hydroclimate over North America

Collaborators:

Active collaboration with Walter Robinson of U. Illinois, David Battisti of U. Washington and Wilco Hazeleger of KNMI

Education and Outreach:

Academic:

Presentations:

Cane: Israeli Society for Ecology and Environmental Quality Sciences International Conference, May 2005

Seminars:

Seager: Rutgers U., September 2004, Gulf Stream and European Climate, U. Chicago, December 2004, North American Drought, U. Maryland, February 2003, North American Drought

Kushnir: MIT, December 2004, North Atlantic Climate Change, Weizmann Institute, May 2005, ENSO and the Global Hydrological Cycle

Cane: Georgia Tech, February 2005, Drought in North America: the solar-ENSO connection

Ting: U. Toronto and Environment Canada, October 2004, Atmospheric stationary wave responses to greenhouse gas increases.

Fellowship Programs / Internships:

Undergraduate

Summer interns have been involved in drought research during summer 2004 and 2005.

Public Relations:

Community Outreach:

Results have been presented at Columbia University's Community Day, which attracts large numbers of visitors from the Morningside Heights, the Upper West Side and Harlem. Results have also been presented at Lamont Doherty's Open House, an event that attracts thousands of visitors including a large number of school students. Seager will give an upcoming talk, open to the public, at the New York Academy of Sciences on the hydrological history of the West. Seager has also appeared on the Weather Channel and given interviews to the media. Cane has frequently provided interviews to the media (Voice of America, BBC) and lectured to Phi Beta Kappa Fellows in April 2005.

Intranet / Internet:

We have prepared a web site on the subject of a paleoclimate and climate modeling perspective on North American drought: (http://www.ldeo.columbia.edu/res/div/ocp/drought/index.shtml)

Databases:

All our climate model simulations are served online for unrestricted instantaneous access: http://kage.ldeo.columbia.edu:81/expert/SOURCES/.LDEO/.ClimateGroup/.PROJECTS/.CCM3/

Personnel:

Research Scientist: 1

Research Support Staff: 4
Administrative: 1
Post Doctoral Fellow: 1
Graduate Student: 1

Publications:

Journal Articles (submitted and in press):

Cane, M. A., 2005: The evolution of El Nino, past and future. Earth and Planetary Science Letters, 230, 227-240.

Clement, A.C. and B. Soden, 2005: The sensitivity of the tropical-mean radiation budget. J. Climate, in press.

Clement, A. C., R. Seager and R. Murtugudde, 2005: On the existence of tropical warm pools. J. Climate, in press.

Hazeleger, W., C. Severeijns. R. Seager and F. Molteni, 2005: Tropical Pacific-driven decadal energy transport variability. J. Climate, 18, 2037-2051.

Herweijer, C., R. Seager and E. R. Cook, 2005: North American Droughts of the mid to late Nineteenth Century: A history, model simulation and implications for Medieval megadrought. The Holocene, submitted.

Herweijer, C., R. Seager and M. Winton, 2005: Why ocean heat transport warms the global mean climate. Tellus, 57A, 662-675.

Herweijer, C. and R. Seager, 2005: The global footprint of persistent extratropical precipitation anomalies: 1856-2003. J. Climate, submitted.

Huang, H.-P., R. Seager and Y. Kushnir, 2005: The 1976/77 transition in precipitation over the Americas and the influence of tropical SST. Clim. Dyn., 24, 721-740.

Mann, M. E., M. A. Cane, S. E. Zebiak and A. C. Clement, 2005: Volcanic and solar forcing of the tropical Pacific over the last 1000 year. J. Climate, 18, 447-456.

Seager, R., Y. Kushnir, C. Herweijer and N. Naik, 2005: Modeling of tropical forcing of persistent droughts and pluvials over western North America: 1856-2000. J. Climate, in press.

Seager, R., W. A. Robinson, N. Harnik, Y. Kushnir, M. Ting, H. Huang and J. Velez, 2005: Mechanisms of ENSO-forcing of hemispherically symmetric precipitation variability. Q. J. Royal. Meteorol. Soc., 131, 1501-1527.

Ting, M. and H. Wang, 2005: The role of the North American topography on the maintenance of the Great Plains summer low-level jet. J. Atmos. Sci., submitted.

Books / Articles-in-Books:

Seager, R. and D. S. Battisti, 2005: Challenges to our understanding of the general circulation: Abrupt climate change. The General Circulation of the Atmosphere, T. P. Schneider and A.S. Sobel, Eds., Princeton University Press, submitted.

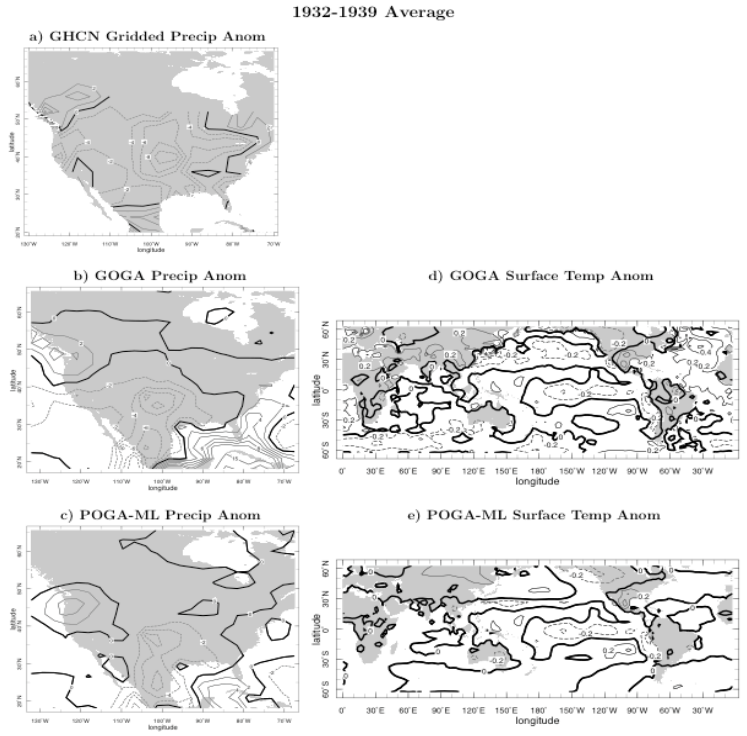
Seager, R., A, Karspeck, M. Cane, Y. Kushnir, A. Giannini, A. Kaplan, B. Kerman and J. Miller, 2004: Predicting Pacific decadal variability, In Earth Climate: The ocean-atmosphere interaction, C. Wang, S.-P. Xie and J. A. Carton, Eds., 105-120.

Conference Proceedings / Workshops:

Observational and modeling requirements for predicting drought on seasonal to decadal timescales (U. Maryland, May 2005, Seager and Ting in attendance, Seager co-organizer).

CCSM Workshop, Colorado, June 2005, MM5 Workshop, Colorado, June 2005 (Ting in attendance)

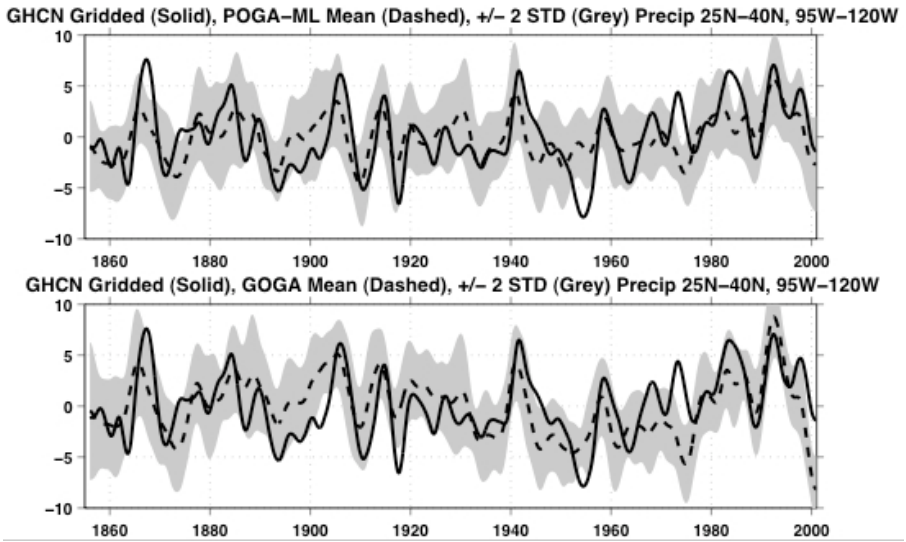
CLIVAR 2004 Conference, Baltimore, Maryland (Ting in attendance)



Results For The 1932 To 1939 Dust Bowl Drought.

(a) The observed precipitation anomaly for the 1932 to 1939 period, (b) the precipitation anomaly from the GOGA ensemble with global SST forcing, (c) the precipitation anomaly from the POGA-ML ensemble with only tropical Pacific SST forcing, (d) the observed SST anomaly and (e) the SST anomaly from the POGA-ML ensemble. Precipitation units are mm per month and SST units are Kelvin.

(a) The precipitation anomaly (mm/month) over the Southwest (120W-95W, 25N-40N) for the period 1856 to 2000 from the POGA-ML ensemble mean and from gridded station data. (b) Same as (a) but with the GOGA ensemble mean. All data has been six year low-pass filtered. The shading encloses the ensemble members within plus or minus of two standard deviations of the ensemble spread at any time.



***Project Title*:** **Dynamical Forecasting of ENSO: A Contribution to the IRI Network**

***Principal Investigator*:** Mark Cane
Affiliation: Lamont-Doherty Earth Observatory

NOAA Program Manager: Dr. Ming Ji, CLIVAR, 301-427-2373, ming.ji@noaa.gov

Research Goals:

To improve our ability to predict ENSO and to make our predictions as usable as possible to the forecasters at application centers. The efforts are focused on forecast system improvements, ENSO predictability, and data assimilation.

Education Goals:

To train students in the area of ENSO research and prediction; to educate public by making real-time ENSO forecast available via our own and others' websites.

Research Progress:

We performed ENSO predictability studies based on an unprecedented retrospective forecast experiment over the past one and a half centuries that we published in Nature. We continued to produce monthly ENSO forecasts with the latest version of the LDEO model, and further strengthened our ties with the forecasters at IRI. We also investigated longer-term aspects of ENSO predictability: decadal predictability and the influence of external forcing.

Predictability of El Niño: roles of the model bias and initial error.

Present estimates of El Niño's predictability are mostly based on retrospective predictions for the last two or three decades, encompassing a relatively small number of events. With so few degrees of freedom, the statistical significance of such estimates is questionable. In principle, predictability can also be estimated by perturbing initial conditions in numerical model experiments, but the answer is model dependent, and existing models have not been shown to be realistic enough for this purpose. El Niño is evident in instrumental observations dating back to the mid 19th century and in proxy data sets over much longer periods, but no successful attempt to hindcast the historic El Niño events, before the mid-20th century has been reported prior to our recent effort. This was due partly to the lack of adequate data for model initialization and partly to the inability of present models to make effective use of available data. Our recent study (Chen et al., 2004a) represents the first retrospective forecast experiment spanning the past one and a half centuries, using only reconstructed sea surface temperature (SST) data for model initialization.

Building up on these results, we used this extended set of ENSO forecast runs for detailed studies of epochal dependence of ENSO predictability using POP analysis and seasonally-dependent Markov models. We also evaluated relative roles, which the growth of the initial error and the impact of internal atmospheric variability play in restricting the model forecast skill when the bias is compensated for via the optimal choice of initial conditions (Karspeck et al 2005).

Operational ENSO forecasting.

We continued to produce seasonal ENSO forecast on a monthly basis. Our forecast is used by IRI in several different ways. In particular, it is used as one of the few members of the IRI ensemble forecasting, thus being an integral part of the official IRI forecasts. Our predictions are also used by NCEP/CPC, and published in the monthly Climate Diagnostic Bulletin and the quarterly

Experimental Long-Lead Forecast Bulletin (Chen et al., 2004bc, 2005ab).

Because of the different requirements of various operational centers, we updated our forecast at least three times a month. Our model output was sent to IRI at the beginning of each month,

to CPC on the 5th, and to COLA in the middle of the month. We reran our model each time to take advantage of new data. Our forecast webpage (http://rainbow.ldeo.columbia.edu/~dchen/forecast.html) is getting updated accordingly. The maintenance of this forecast system required retuning of the system every time when the nature of the input data streams change (e.g. CLS altimetry and FSU wind data analysis methodology and analyzed grids changed). A suite of forecast experiments had to be run to ensure a smooth transition.

We have retuned the latest version of our model, LDEO5, for our operational predictions. This is the bias-corrected model used successfully for the long-term experiment discussed above (Chen et al. 2004a). The main improvement was a better assimilation of SST data. This was achieved by including a bias correction term in the model SST equation that statistically corrects for model deficiencies in parameterizing subsurface temperature and surface heat fluxes.

Highlights:

- Use of LDEO5 in operational predictions of ENSO events.
- Initial evaluation of ENSO predictability from long (~150 years) series of retrospective forecasts and analyses of observed data.
- Evaluation of relative roles of the initial error and the internal atmospheric variability play on restricting the model forecast skill.
- Use of the model for ENSO predictions to study the predictability of Pacific decadal variability and the impact of external forcing on ENSO variability

Societal Benefits:

- ENSO variability has a profound influence on year-to-year climatic changes experienced by American public and people around the world. This project strives to improve predictions of ENSO events and investigates the nature of this predictability and its limiting factors.
- This project also contributes towards the emerging understanding of the interactions between ENSO variability and global change: another issue of significant public interest

CICAR / NOAA Funded Research Connections:

Research Partnerships:

IRI-ARCs network

Collaborators:

S. Zebiak, D. DeWitt, M. Tippett (all IRI)

Education and Outreach:

Academic Outreach:

K-12:

Elizabeth Heller was mentored by A.Kaplan within the Nanuet High School Authentic Science Research Program. Her paper "An Evaluation of the 1868 El Nino" was selected for Finals in the 2004 Intel Science Talent Search competition. Ms. Heller is currently a Vassar College student.

Research Advisor / Mentor:

Undergraduate:

A.Kaplan/M. Richard (Ecole Polytechnique, France)

Graduate:

M.A.Cane/A.Karspeck (Ph.D from Columbia 2004, currently NOAA Global Change postdoctoral Fellow in NCAR, Boulder, CO)

Academic:

Seminars:

Kaplan, A., "Small-scale variability in sea surface heights and surface winds: Implications for errors in ocean models and observations." Oregon State University, Physical Oceanography Seminar Series, March 10, 2005.

Fellowship Programs / Internships:

LDEO REU and IGERT Summer Internships

Intranet / Internet:

http://rainbow.ldeo.columbia.edu/~dchen/forecast.html

http://www.iges.org/ellfb/Jun05/Chen/chen.htm

http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/bulletin_0605/figf7.html

http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/bulletin_0605/figf8.html

http://iri.columbia.edu/climate/ENSO/currentinfo/SST_table.html

Personnel:

Research Scientist:	4 (2 at no cost)
Research Support Staff:	2
Administrative:	1
Graduate Student:	1
Undergraduate Student:	1

Personnel funded by this project and obtaining NOAA employment within the last year: 1

Name:	Alicia Karspeck
NOAA Agency / Lab:	The National Center for Atmospheric Research (NCAR) Boulder, Co.
Date of Hire / Appointment:	December 31, 2004
Title / Duties:	Postdoctoral Research Fellow / Independent research
Acceptance Date:	April 15, 2004
Start Date:	December 31, 2004

Publications:

Journal Articles (submitted and in press):

Karspeck, A. R., R. Seager and M. A. Cane, 2004: Predictability of tropical Pacific decadal variability in an intermediate model. *Journal of Climate*, **17**(14): 2842-2850.

Cane, M. A., 2005: The evolution of El Nino, past and future. *Earth and Planetary Science Letters*, **230**(3-4): 227-240

Mann, M. E., M. A. Cane, S. E. Zebiak and A. Clement, 2005: Volcanic and solar forcing of the tropical Pacific over the past 1000 years. *Journal of Climate*, **18**(3): 447-456.

Karspeck, A.R., A. Kaplan, M.A. Cane, 2005: Predictability loss in an intermediate ENSO model due to initial error and atmospheric noise, *J.Climate*.

Books / Articles-in-Books:

Seager, R., A. Karspeck, M. Cane, Y. Kushnir, A. Giannini, A. Kaplan, B. Kerman, J. Velez, 2004: Predicting Pacific decadal variability. *Ocean-Atmosphere Interaction and Climate Variability.* C. Wang and S.-P. Xie and J. A. Carton, ed., American Geophysical Union, Washington, DC, pp.115-130.

Reports:

Chen, D., S. E. Zebiak, M. A. Cane, 2004b: Experimental forecast with the latest version of the LDEO model (March). Experimental Long-Lead

Forecast Bulletin, 13, 3 (September 2004).

Chen, D., S. E. Zebiak, M. A. Cane, 2004c: Experimental forecast with the latest version of the LDEO model (March). Experimental Long-Lead Forecast Bulletin, 13, 4 (December 2004).

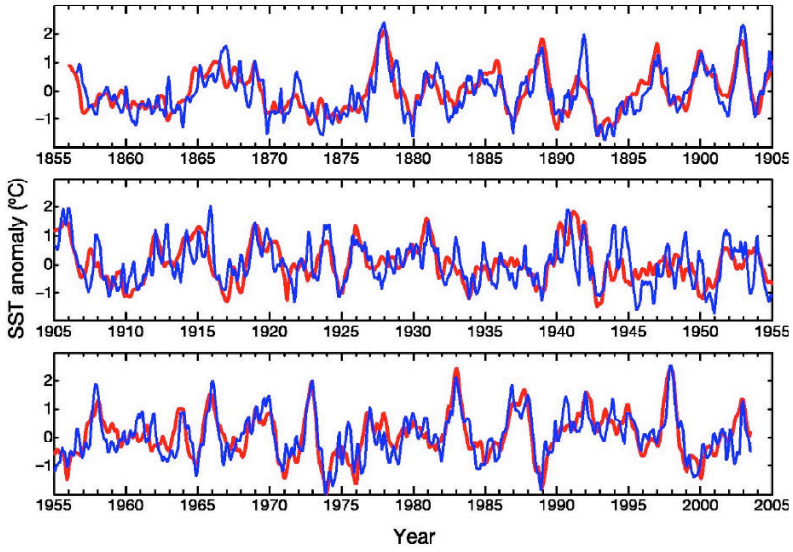
Chen, D., S. E. Zebiak, M. A. Cane, 2005a: Experimental forecast with the latest version of the LDEO model (March). Experimental Long-Lead Forecast Bulletin, 13, 1 (March 2005).

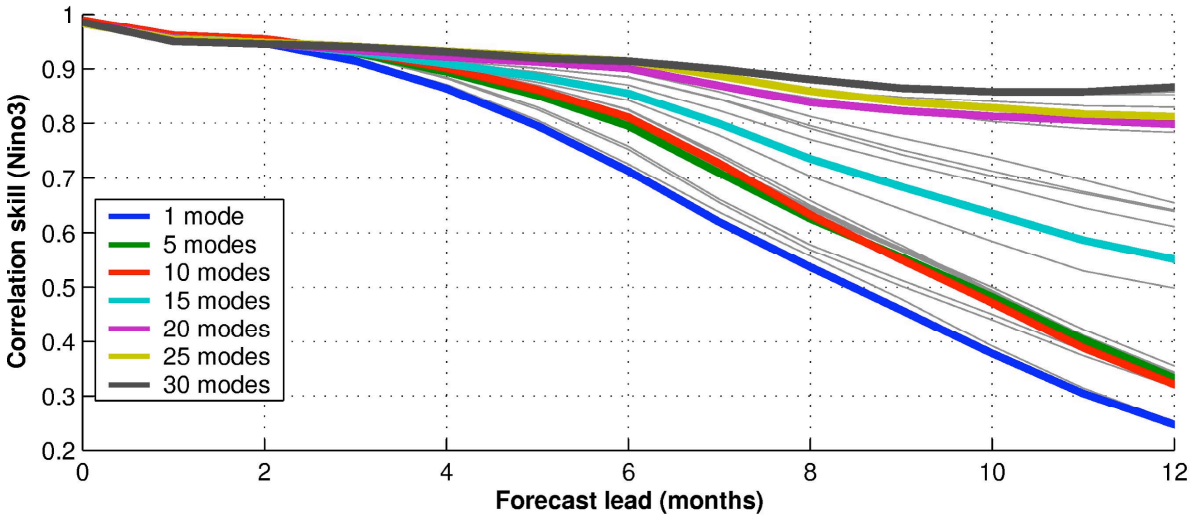
Chen, D., S. E. Zebiak, M. A. Cane, 2005b: Experimental forecast with the latest version of the LDEO model (March). Experimental Long-Lead Forecast Bulletin, 13, 3 (June 2005).

Ph.D. Dissertations:

Karspeck, A., 2004: *Predictability of ENSO on interannual and decadal timescales.* Ph.D. dissertation, Columbia University, 2004. Advisor: M.A.Cane, co-advisors: A.Kaplan, M.Visbeck.

Retrospective Predictions Of El Nino And La Nina In The Past 148 Years
Time series of SST anomalies averaged in the NINO3.4 region (5S-5N, 120-170W). The red curve is from the analysis of historical ship data by Kaplan et al. (1998), and the blue curve is the LDEO5 prediction at 6-month lead. [Adopted from Chen et al. 2004a]





The Correlation Skill Of LDEO4 When Initialized With The ``Best'' Initial Conditions
[Adopted from Alicia Karspeck's Ph.D. dissertation, Columbia University, 2004]

Project Title: **Describing, Understanding, and Predicting Oceanic Variations Associated with Tropical Atlantic Variability and The North Atlantic Oscillation**

Principal Investigator: Dake Chen
Affiliation: Lamont-Doherty Earth Observatory

NOAA Program Manager: Dr. James Todd, CLIVAR Atlantic, 301-427-2089 Ext. 2383, james.todd@noaa.gov

Research Goals:

The goals in the first year of this multi-institute research project are data collection, processing, and analysis. At LDEO, we extended our objectives to include preliminary numerical experiments to evaluate the effects of anomalous precipitation on tropical ocean modeling and to explore the uncertainty of surface buoyancy forcing.

Research Progress:

The progress we made during this year has exceeded the established objectives. We have collected and processed six different precipitation datasets, including CMAP, NCEP, GPCP, TRMM, OPI and GPI, and performed various analyses on them along with other observed atmospheric and oceanic variables such as wind and SST. More importantly, we have carried out two sets of model experiments with the Lamont OGCM, one to evaluate the impact of the anomalous precipitation from CMAP on tropical ocean simulation over the period 1979-2003, and the other to examine the different oceanic responses to the various precipitation forcing.

An example of the first set of experiments is displayed in Figure1, where the effects of anomalous precipitation on model temperature and salinity fields are shown for El Niño and La Niña conditions, respectively. During the mature phase of El Niño, surface salinity increases in the western Pacific and eastern Indian Ocean warm pool and, to a lesser extent, in the equatorial Atlantic Ocean, whereas it decreases in the central-eastern Pacific and western Indian Oceans. This is obviously consistent with the zonal movement of convention centers. The resulting SST changes are as expected: higher/lower SST corresponds to lower/higher SSS because of the shallower/deeper surface mixed layer caused by buoyancy flux variation. The situation is generally the opposite during the mature phase of La Niña. It is worth noting that the effects of anomalous precipitation extend far beneath the surface layer, especially for temperature, indicating a dynamic response and associated thermocline fluctuation.

A comparison of the six different precipitation products and their effects on the tropical Atlantic SSS and SST is shown in Figure 2, in terms of the standard deviation, a measure of interannual variability, of both the forcing and the model response. As evident in the case of CMAP, the oceanic precipitation in the tropical Atlantic has the largest variance in the western equatorial Atlantic and along the ITCZ, whereas the SSS and SST variances are more confined to the east. This again suggests that the ocean response to the anomalous precipitation is dynamic as well as thermodynamic. As compared to CMAP, the variances of the other five precipitation products differ not only in magnitude but also in spatial pattern. The uncertainty in precipitation forcing, as measured by the differences among the various products, can be as large as the variability of each forcing, which can result in significant errors in model simulation. This uncertainty is a serious problem facing climate modelers at present.

Highlights:

- The interannual variability of precipitation has a significant impact on the upper ocean dynamics and thermohaline structure in the tropics.
- At present, the uncertainty in precipitation forcing can be as large as the variability of each forcing, and so is the uncertainty in the resulting model response.

Societal Benefits:

Our study aims at a better understanding, description, and prediction of Atlantic oceanic precipitation, which will directly benefit the surrounding countries of the Atlantic Ocean.

CICAR / NOAA Funded Research Connections:

Interagency:

This research is an integral part of our long-standing effort on climate prediction funded by NOAA, NASA and NSF.

Research Partnerships:

The success of the research depends on the partnerships among LDEO, CPC/NCEP and UMD.

Collaborators:

P. Xie (CPC), Y. Xue (CPC), P. Arkin (UMD), Z. Wang (LDEO).

Personnel:

Research Scientist: 1
Research Support Staff: 1

Publications:

Journal Articles (submitted and in press):

Chen, D., P. Xie, Y. Xue, P. Arkin and Z. Wang, 2005: Impact and uncertainty of interannual precipitation variability over the tropical oceans. *J. Geophys. Res.,* submitted.

Describing, Understanding, and Predicting Oceanic Variations Associated with Tropical Atlantic Variability and The North Atlantic Oscillation

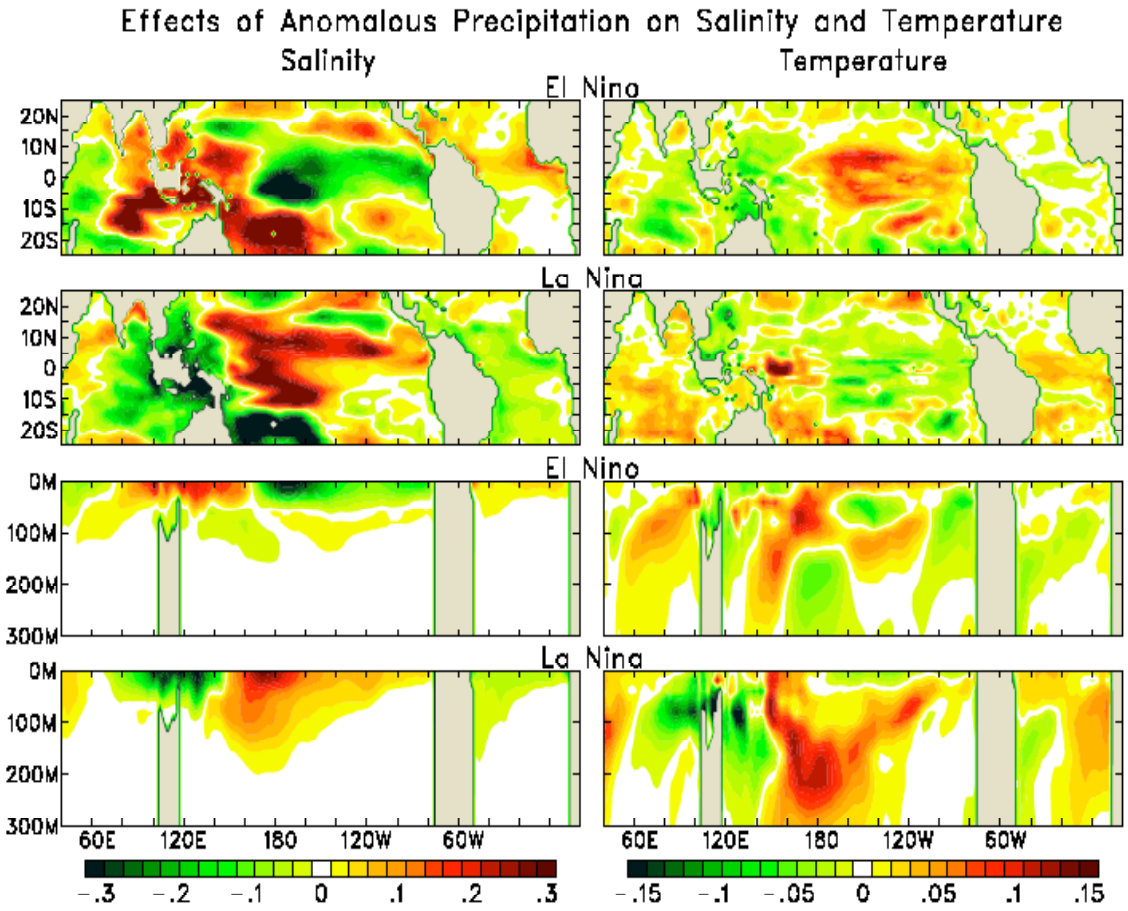


Figure 1. Composites of model salinity and temperature anomalies due to anomalous precipitation in December-January-February of El Niño and La Niña years, respectively. The upper two rows are latitude-longitude plots at the surface of the tropical oceans, whereas the lower two rows are depth-longitude plots along the equator (5°S-5°N). These are obtained by taking the difference between model runs with and without the anomalous CMAP precipitation. It is clear that the interannual variability of precipitation has significant effects on the thermohaline structure of the tropical oceans, and that such effects are not limited to the sea surface.

Project Title: **Multivariate Approach to Ensemble Reconstruction of Historical Marine Surface Winds from Ships and Satellites**

Principal Investigator: Alexey Kaplan
Affiliation: Lamont-Doherty Earth Observatory

NOAA Program Manager: Dr. Christopher D. Miller, Climate Change Data and Detection/Climate Observations, 301-427-2376, Christopher.d.miller@noaa.gov

Research Goals:

- Developing adequate techniques for multivariate analyses of winds and related variables.
- Use of objective multivariate analysis approach for removing spurious long-term trends in wind data.
- Developing and utilizing the procedure for representing the analysis uncertainty by an ensemble of possible realizations.
- Applying newly developed products for addressing relevant questions about Indian monsoon -- global warming connections and genesis of the PDO

Education Goals:

Historical analyses of ocean surface winds developed in this project will be used in research projects of students in our group and outside. Making the analyses available via web-interfaced data server ensures wide accessibility of the results for educational purposes.

Research Progress:

We commenced this project by (1) producing trial versions of ocean surface wind and sea level pressure data sets for the latest COADS version, using the previously developed univariate reduced space analysis technique; (2) comparing the results of these trial analyses with other wind products that are based on different techniques, or use satellite data, or numerical models; (3) evaluating trial analyses in the context of other climate variables; (4) estimating small-scale variability in wind fields, its role in the analyses error and its role as forcings for ocean models, and advancing the ways of representing the uncertainty in the analyzed values.

1**. Trial data set development**

Releases 1c and 2 of the Comprehensive Ocean Atmosphere Data Set pushed the compilations of marine observations from ship reports back to around 1800. The 19th century exhibits dramatic changes in the marine data availability, from on the order of 1000 reports per year in the first two decades to a quarter of million reports per year at the close of the century. We applied the reduced space objective analysis technique to reconstruct near-global 19th century fields of sea level pressure and surface winds with spatial resolution of 4 degrees and monthly or annual temporal resolution. The quality of these trial reconstructions changes significantly with the amount of available data.

2. **Comparison with other analyses**

Comparison of the tropical Pacific surface zonal wind stress from four products for a 30 year period 1964-1993 (da Silva successive correction analysis, our trial reduced space optimal interpolation computed for global surface winds, NCEP-NCAR reanalysis, and the FSU subjective analysis of tropical Pacific winds) shows completely different trends, poor overall coherency (an area averaged correlation coefficient between any two products does not exceed 0.56), and substantial difference in the degree of the spatial and temporal smoothness. Nevertheless, certain large-scale aspects of interannual variability seem to be faithfully reproduced and can be reconstructed on the basis of historical data.

3**. Trial analyses in the context of other climate data and model simulation**s

Averages of tropical sea level pressure showed variability consistent with other observation-based analyses (including atmospheric reanalyses; this comparison helped to identify a failure of atmospheric GCMs to reproduce a steep increase in the tropical atmospheric mass after the

1974-75 PDO transition (Seager et al 2004). Central equatorial Pacific zonal wind values proved to be quite consistent with other indices of the interannual ENSO variability and helped to identify the variability in the Hadley circulation of the Pacific sector in the last 150 years (Evans and Kaplan, 2004).

4**. Comparison of the performance of various tropical wind products as forcings for an ocean model identified the equatorial persistence as a crucial controlling factor**
This can be easily explained in the context of the general dependence of the tropical sea level and thermocline response to the small-scale variability ('noise'') in winds (Kaplan et al. 2004). Satellite data allowed us to estimate the pattern of the small-scale variability in the surface winds and helped to identify a remarkable level of the month-to-month persistence of the equatorial winds anomaly, which could not be identified from the ship data alone. The trial wind analyses and their error estimates were successfully used in ENSO predictability by A.Karspeck in her Ph.D. dissertation (2004). More sophisticated approaches to describing the uncertainty in analyzed values will follow the hierarchical Bayesian regression approach applied recently by us to the bias analysis of the SST data (Kent and Kaplan, 2005).

Highlights:

- Reconstructions of pressure and surface winds on the basis of new I-COADS compilations,
- Verifiable skill of interannual variability of central equatorial Pacific winds,
- Remarkable persistence of interannual wind anomalies and its importance for the wind-forced tropical ocean simulations.

Societal Benefits:

- We develop wind data sets that help to understand and perhaps predict climate changes. The critical importance of surface wind data for climate variability and climate change studies is well recognized. This project responds to this scientific need.
- National and international climate change assessments (like IPCC) serve to the benefit of the society and scientific community. We work on the data set which will lengthen significantly wind data sets available for climate simulations, and which will provide the user with a straightforward way to take its uncertainty into account. We also expect wide utilization of our products in statistical studies of climate variability, for calibration and verification of paleoclimatic reconstructions, etc.

Education and Outreach:

Academic Outreach:

K-12:

Elizabeth Heller was mentored by A.Kaplan within Nanuet High School Authentic Science Research Program. Her paper "An Evaluation of the 1868 El Nino" was selected for Finals in the 2004 Intel Science Talent Search competition. She is currently a Vassar College student.

Postsecondary:

Shane Riordan, science high school teacher from New York Harbor HS is doing summer 2005 research project with A. Kaplan in the framework of Columbia Science Teachers Science Research Program.

Research Advisor / Mentor:

Undergraduate:

A.Kaplan/T.Merlis (Columbia Engineering School senior, Applied Math)

Graduate:

M.A.Cane/A.Karspeck (Ph.D from Columbia 2004, currently NOAA Global Change postdoctoral Fellow in NCAR, Boulder, CO)

Presentations:

Kaplan A. Estimates of signal, uncertainty, and physical constraints in objective analyses of vertical temperature profiles. International Workshop on Understanding Vertical Profiles of Temperature Trends, Hadley Centre, UK Met Office, Exeter, UK.

Seminars:

Kaplan, A., "Small-scale variability in sea surface heights and surface winds: Implications for errors in ocean models and observations." Oregon State University, Physical Oceanography Seminar Series, March 10, 2005.

Intranet / Internet:

http://www.cgd.ucar.edu/~asphilli/DataCatalog/Data/kaplan.html

Databases:

http://ingrid.ldgo.columbia.edu/SOURCES/.KAPLAN/.RSA_COADS_SLP1.cuf/.dataset_documentation.html

http://www.cdc.noaa.gov/Pressure/Gridded/data.kaplan_slp.html

Personnel:

Research Scientist: 3
Graduate Student: 1
Undergraduate Student: 1

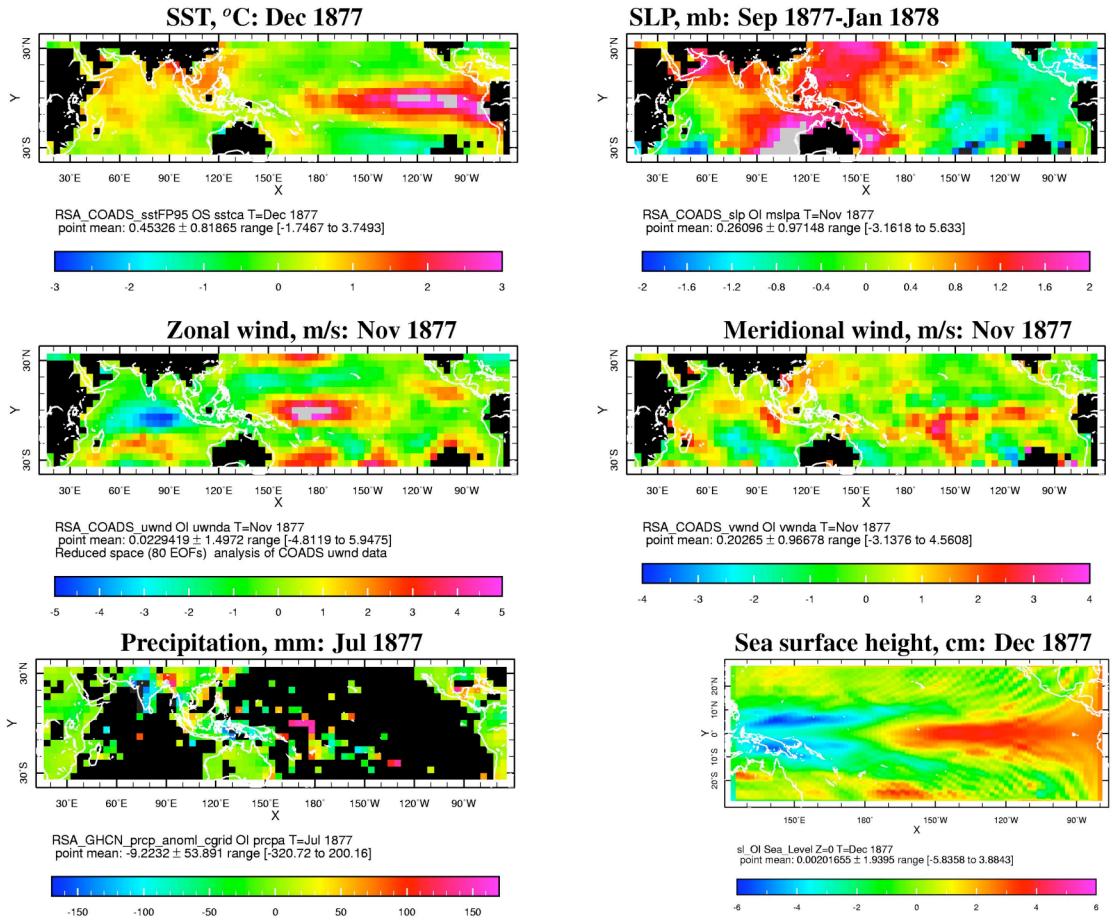
Publications:

Journal Articles (submitted and in press):

Kent, E.C. and A. Kaplan, 2005: Towards estimating climatic trends in SST. Part 3: Systematic biases, J. *Atmos. Oceanic Technol.*, in press.

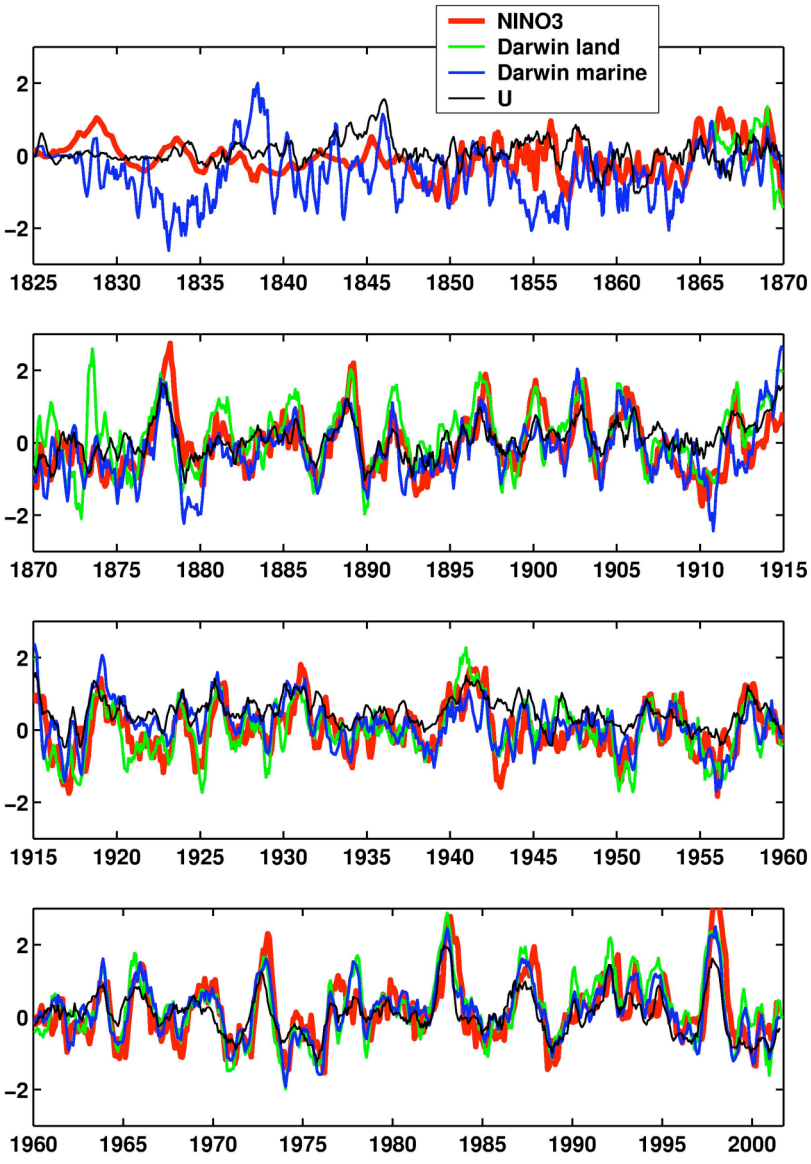
Karspeck, A.R., A. Kaplan, M.A. Cane, 2005: Predictability loss in an intermediate ENSO model due to initial error and atmospheric noise, *J.Climate*, revised.

El Niño of 1877-1878 in analyzed anomalies



Anomalies Of 1877-1878 El Nino Illustrated By Univariate Reduced Space Analyses

Multivariate Approach to Ensemble Reconstruction of Historical Marine Surface Winds from Ships and Satellites



Intercomparison of ENSO indices: NINO3, degree C, by Kaplan et al. [1998]; Darwin station SLP, mb, [Allan et al., 1991];
Darwin area SLP estimate from ship-based RSOI, mb, [*Kaplan et al.,* 2000]; and Central Equatorial Pacific zonal wind anomaly (5S-5S,160E-120W), 5m/s from the ongoing CICAR project. Pressure and wind data are 5 month running means. [Adapted from *Evans and Kaplan*, 2004].

Project Title: **South Atlantic Ocean-Atmosphere Interaction**

Principal Investigator/s: Andrew Robertson
Affiliation: IRI – International Research Institute for Climate Prediction

NOAA Program Manager: Dr. James Todd, CLIVAR Atlantic NOAA/OGP, 301-427-2089 Ext. 2383, james.todd@noaa.gov

Research Goals:

Seasonal climate forecasts over tropical Africa and South America are hampered by the lack of skillful predictions of sea surface temperatures (SST) in the tropical Atlantic. The mean seasonal cycle and variability of the tropical Atlantic are closely linked to the South Atlantic through the subtropical anticyclone and shared modes of SST variability. In particular, it is hypothesized that the interactions between the El Niño-Southern Oscillation during boreal spring with pre-existing upper-ocean anomalies over the South Atlantic Ocean yield increased predictability of tropical Atlantic variability (TAV). The goal of this project is to make advances in two areas in order to improve seasonal prediction over the tropical Atlantic: (1) physical understanding of ocean-atmosphere interactions over the South Atlantic and their interactions with ENSO and TAV, and (2) simulation of the mean climate and seasonal cycle by coupled ocean-atmosphere general circulation models (GCMs) over the South Atlantic, as a prerequisite to successful dynamical seasonal prediction over the Atlantic sector.

Research Progress:

The project is organized as two parallel efforts at IRI and UCLA. The IRI component is focused on interannual variability and predictability (topic 1), while a better dynamical understanding of errors in the mean seasonal cycle is the focus of the UCLA component.

IRI Component: Physical understanding of ocean-atmosphere interactions over the South Atlantic and their interactions with ENSO and interannual TAV

During the initial stage of the project, we have explored the hypothesis that preconditioning of the Atlantic's response to ENSO can yield an important source of seasonal predictability, as proposed by Giannini et al. (2004). This work is in preparation for hindcast experiments to quantify the usefulness of this source of predictability, using an atmospheric GCM coupled to a simplified ocean model.

The influence of El Niño on South Atlantic is investigated in the context of the meridional SST gradient across the tropical Atlantic. This gradient, denoted as G1 and defined as the difference between the North Atlantic SST (tNA) averaged over 5N-25N and South Atlantic SST (tSA) over 5S-25S, is known to regulate rainfall over the northern Brazil. Previously, Giannini et al. (2004) found that for 1950-1994 El Niño events are dominated by those with a negative G1 (South Atlantic warmer than North Atlantic) in March-May, called "discordant" cases (with opposite signs for NINO3 index and G1), while La Niñas are dominated by "concordant" cases. Using a long and detrended SST data set for 1876-1999, we clarified that concordant cases are actually more common than discordant ones for both El Niño and La Niña. This is consistent with our further analyses of the lag correlation between the NINO3 index and tNA, tSA, and G1, performed using the same SST data for 1876-1999. The NINO3 index in January is found to be positively correlated with both tNA and tSA in March-May. However, the correlation between NINO3 and tNA is 0.6 compared to 0.3 for that between NINO3 and tSA. Consequently, the sign of (tNA-tSA) more often than not agrees with that of the tropical Pacific SST anomaly associated with ENSO.

The weak correlation between El Niño SST and tSA indicates a substantial non-ENSO influence due to local dynamics in the South Atlantic. Searching for hints of the local processes, we found that in the composite of the concordant cases described above a distinctive structure of SST anomaly exists off the coast of Angola and extends northwestward (covering part of the

tSA region) to near the equatorial Atlantic. This pattern broadly resembles the so-called Benguela Niño (Florenchie et al. 2004); the strongly concordant cases are those with a warm (cold) ENSO event coinciding with a cold (warm) Benguela Niño. This picture did not emerge clearly in a similar composite in Giannini et al. (2004), likely because the shorter SST record they used does not contain a large enough number of Benguela Niño events (which occur less frequently than El Niños). As the oceanic upwelling pertinent to Benguela Niño is located beneath the northward branch of the South Atlantic anticyclone, the relationship between the two and their further connection with ENSO will be investigated.

Highlights:

- Confirmed from an 1876–1999 data record that the meridional gradient of sea surface temperature in the tropical Atlantic during March–May is more often consistent with the remote response to ENSO
- Identified the Benguela Niño as a potentially important precursor to tropical Atlantic variability

Societal Benefits:

Accomplishments are an important first step in identifying predictable components of climate in the South Atlantic, in order to improve the skill of seasonal predictions of the West African Monsoon; the latter is of great societal importance to the countries of West Africa.

CICAR / NOAA Funded Research Connections:

Research Partnerships:

This project is in partnership/collaboration with Profs. C. R. Mechoso and A. Hall at UCLA's Department of Atmospheric and Oceanic Sciences.

Academic:

Symposiums:

Huang, H.-P., A. W. Robertson, and Y. Kushnir, 2005: Atlantic SST gradient and the influence of ENSO. *U. S. CLIVAR Atlantic Science Conference* January 31– February 2, 2005, RSMAS, Miami.

Personnel:

Research Scientist: 2 (at no cost)
Post Doctoral Fellow: 1

Project Title: **The Role of Orography on the North American Monsoon Onset and Interannual Variability**

Principal Investigator: Mingfang Ting
Affiliation: Lamont-Doherty Earth Observatory

NOAA Program Manager: Dr. Michael Patterson, CPPA, 301-427-2089, michael.patterson@noaa.gov

Research Goals:

The goal of this project is to develop a better understanding of the onset and interannual variability mechanisms for the North American Monsoon system (NAM). In particular, we are interested in the role of North American topography in the NAM rainfall onset and interannual variability.

Research Progress:

We have focused on two main activities in this project during the past year, one on dynamical understanding of the role of North American topography on the maintenance of low-level jet and the United States summer precipitation and the other on down-scaling the United States precipitation using regional climate model for both the case with and without North American topography.

GCM experiments using both the GFDL AM2 and the NCAR CCM3 are performed to test the role of North American topography on the Great Plains low-level jet and the United States precipitation. Results show that the Great Plains low-level jet disappears completely in the experiment when the North American topography is removed, while the summer seasonal mean low-level jet is well simulated in the experiment with the realistic topography. In the absence of the North American topography, the summer precipitation is significantly reduced over the central United States and increased along the Gulf States and northeast Mexico.

Linear and nonlinear stationary wave models are used to determine the physical mechanisms through which the North American topography maintains the Great Plains time mean low-level jet. Possible mechanisms include the physical blocking of the topography and the induced flow over and around the mountains, the thermal effect due to the elevation of the mountains, and the transient thermal and vorticity forcing due to the modification of transient eddy activities in the presence of the mountains. The linear and nonlinear model results indicate that the dominant mechanism for maintaining the time mean Great Plains low-level jet is through the nonlinear effect of the trade wind along the southern flank of the North Atlantic subtropical high encountering the east slope of the Sierra Oriental and causing the flow to turn northward. As the flow turns north along the east slope of the North American topography, it obtains anticyclonic shear vorticity and thus the low-level jet. The effect of the thermal forcing is negligible, while the effect of transient forcing is only important in extending the jet further northward and eastward. The results suggest that variations in the strength of the North Atlantic subtropical anticyclone and the associated trade wind over the Caribbean and the Gulf of Mexico may be important for understanding the interannual variation of the Great Plains low-level jet and the United States summer precipitation. A paper summarizing the results based on the GFDL model experiments and the linear and nonlinear model diagnostics is submitted to the Journal of the Atmospheric Sciences in February and is conditionally accepted (Ting and Wang, 2005). The output from the CCM3 experiments with and without North American topography is currently being analyzed and is being coupled to the regional climate model to downscale the United States precipitation, particularly the North American monsoon precipitation. Results based on the CCM3 and regional climate model (CMM5) will be presented at the joint WRF/MM5 users' workshop in Boulder, Colorado in June (Ting et al., 2005).

In addition to the above diagnostic works, significant progress has been made in the regional climate modeling of the North American precipitation. The regional climate model developed at the Illinois State Water Survey (Liang et al., 2001) has been demonstrated to have significant downscaling skills for the North American precipitation (Liang et al., 2004). Regional model experiments were carried out for the North American region with prescribed NCEP-DOE AMIP II reanalysis lateral boundary conditions (LBCs) for the period 1982-2002. The precipitation simulation is most skillful in the Northwest, where orographic forcing dominates throughout the year; in the Midwest, where mesoscale convective complexes prevail in summer; and in the central Great Plains, where nocturnal low-level jet and rainfall peaks occur in summer. We are currently preparing a journal article on the CMM5 downscaling skill of interannual variations of the North American precipitation. In particular, we will address the physical processes associated with the North American monsoon and its link to the Midwest precipitation systems.

Highlights:

- Determined the role of North American topography on the maintenance of low-level jet and the United States summer precipitation
- Demonstrated the regional climate model downscaling skills for North American summer precipitation

Societal Benefits:

The results from this project improves our understanding of the NAM rainfall, its relation with Great Plains summer precipitation, and helps with the seasonal forecast of the US precipitation during the summer.

CICAR / NOAA Funded Research Connections:

Research Partnerships:

University of Illinois State Water Survey

Collaborators:

Dr. Xin-Zhong Liang

Personnel:

Research Scientist: 1
Post Doctoral Fellow: 1

Publications:

Journal Articles (submitted and in press):

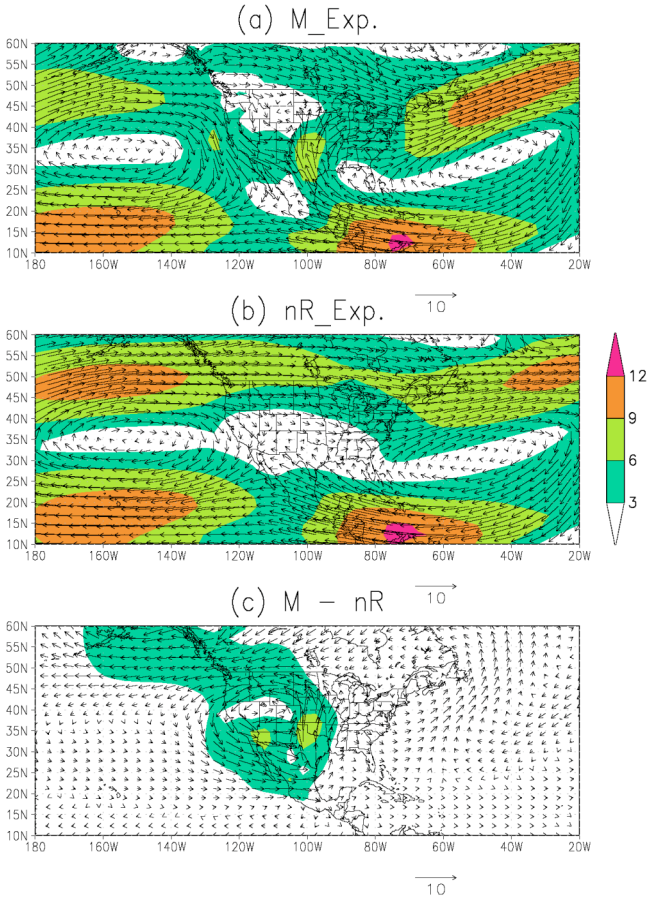
Liang, X.-Z., L. Li, K. Kunkel, M. Ting, and J. X.-L. Wang, 2004: Regional Climate Model Simulation of U.S. Precipitation during 1982-2002. Part I: Annual Cycle. *J. Climate*, **17**, 3510-3529.

Ting, M., and H. Wang, 2005: The Role of the North American Topography in the Maintenance of the Great Plains Summer Low-Level Jet. *J. Atmos. Sci.*, in print.

Conference Proceedings / Workshops:

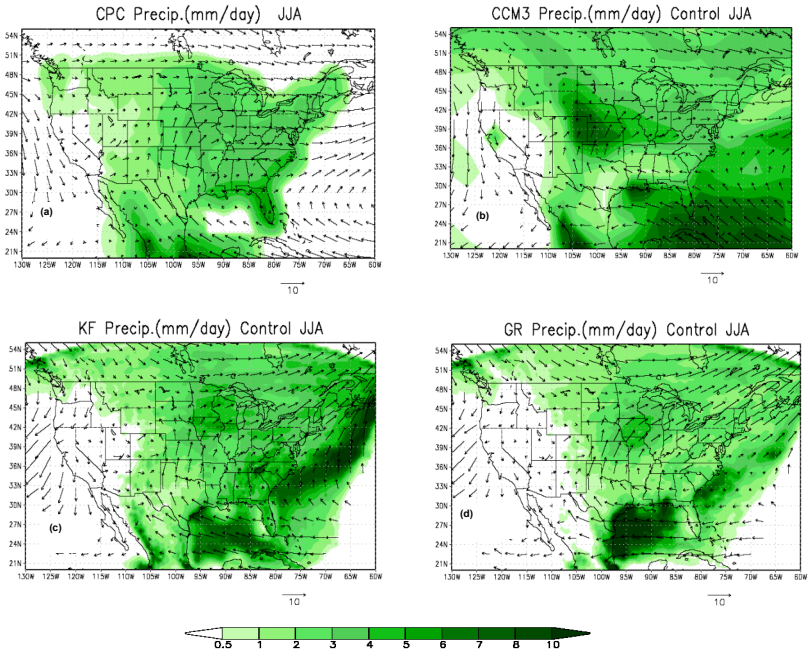
Ting, M., X. Liang, J. Pan, H.-P. Huang, 2005: Seasonal Cycle of North American Precipitation with and without topography in CCM3 and the MM5-based Regional Climate Model. Abstract submitted to the Joint WRF/MM5 Users' Workshop, June 2005, Boulder, Colorado.

The Role of Orography on the North American Monsoon Onset and Interannual Variability



850 Mb Wind Vectors And Magnitude (Shadings) For The GFDL GCM Experiment With Full Earth Topography

(a), without the North American topography (b), and the difference between (a) and (b). Wind vector and shading scale is as shown (in m/s).



June, July, And August Seasonal Average Precipitation Over The United States From NOAA CPC Rain Gauge Observations

(a), CCM3 simulation with prescribed climatological SST (b), CMM5 simulation with K-F convective scheme and CCM3 lateral boundary conditions (c), and CMM5 simulation with Grell convective scheme (d).

Project Title: **The Role of Ocean Dynamics in Tropical Atlantic SST**

Principal Investigator: Martin Visbeck
Affiliation: Lamont-Doherty Earth Observatory

NOAA Program Manager: Dr. James Todd, CLIVAR Atlantic, 301-427-2089 Ext. 2383, james.todd@noaa.gov

Research Goals:

- Investigate the mechanisms of tropical Atlantic climate variability with an emphasis of the role of tropical ocean dynamics in seasonal to interannual climate prediction.
- Correct model biases in the tropical Atlantic Ocean

Research Progress:

Most of the work during this year of study was dedicated to solve issues with model biases in the equatorial Atlantic simulations with the Lamont ocean GCM. As many other models of its kind, the model climatology in this region is wrong in that it does not simulate the seasonal (boreal summer) cooling in the eastern equatorial Atlantic (so called the Atlantic cold tongue region). We experimented with various methods of flux correction but while these, by definition, addressed the model climatological biases, did not result in an improved simulation of the interannual variability. Our results suggest that discrepancies in surface forcing as the main cause of errors in the simulation of interannual variability.

Highlights:

- Surface wind forcing errors are the main reason for ocean model discrepancies in simulating the interannual variability of the tropical Atlantic.

Societal Benefits:

This ocean-modeling project aims at improving model simulation of interannual variability in the tropical Atlantic, an area where climate anomalies have large societal impacts in areas of water resources, agriculture and health. Improving climate model simulations has the potential to lead to advance climate prediction for this region.

CICAR / NOAA Funded Research Connections:

Research Partnerships:

This project has linkages to international efforts to better understand and simulate climate prediction in the tropical Atlantic. Data from this modeling project was shared with other international institutions thought the NOAA and NSF supported TACE (Tropical Atlantic Climate Experiment).

Personnel:

Research Scientist: 2 (1 at cost)
Research Support Staff: 1
Graduate Student: 1

Theme II: Modern and paleoclimate observations

Abrupt Climate Change Studies (ARCHES) Paleoclimate Research:

Project Title:	**ARCHES: Paleo Sea-Ice Distributions**
Principal Investigator:	Robert F. Anderson
Affiliation:	Lamont-Doherty Earth Observatory
NOAA Program Manager:	Dr. James Todd, CLIVAR Atlantic, 301-427-2089 Ext. 2383, james.todd@noaa.gov

Research Goals:

This project has two broadly defined objectives:

1. To calibrate (improve) and later apply transfer functions (algorithms) designed to reconstruct sea ice distributions in the Southern Ocean based on the assemblage of diatom species preserved and buried in sediments. This objective has been modified during the latter half of this project to explore and develop a new proxy, based on the abundance of Interplanetary Dust Particles in sediments, for freshwater supply by melting icebergs.
2. To develop high-resolution records of changes in the ventilation (the degree to which the gases in water are equilibrated with the atmosphere) of Southern-Source Deep Water through periods of Abrupt Climate Change.

Ultimately these two objectives will be integrated in that sea ice cover and meltwater supplied by melting icebergs influences the ventilation of newly-formed deep water, as well as having a major impact on air-sea fluxes of heat, moisture, and momentum.

Research Progress:

Sea Ice Reconstruction / Iceberg Melting

Freshwater supplied by the melting of icebergs influences the density of surface waters in the polar ocean. This, in turn, affects the Meridional Overturning Circulation (MOC) of the ocean. A longstanding question in paleoclimate research has been whether or not similar surges of the Antarctic ice sheet have occurred and, if so, what impact they had on MOC of the Southern Ocean, on the associated heat transport and, therefore on earth's climate. This problem has been intractable until now.

We have been developing and exploring Interplanetary Dust Particles (IDPs) as a proxy for freshwater released by melting icebergs. IDPs are delivered to the Earth's surface from space. Evidence to date suggests that the delivery is uniform in space and time. Therefore, the rate of IDP delivery to the surface of the Antarctic ice sheet is well known. When icebergs melt, the IDPs are released and they sink to the seabed.

IDPs contain very high concentrations of Helium-3, the rare isotope of helium – many orders of magnitude higher than are found in terrestrial rocks. Therefore, we can estimate the abundance of IDPs in sediments by measuring the concentration of extraterrestrial 3He.

During the past year we measured a profile of 3He concentrations in a core from the Atlantic sector of the Southern Ocean. Sea ice concentrations and many other climate proxies had already been measured in this core, so we were starting with a robust record of climate change at this site. Many climate features are displayed prominently in these records, including the Last Glacial maximum, the rapid warming beginning about 17 ka BP, the Antarctic Cold Reversal, the Antarctic Climatic Optimum, and the neoglaciation that characterizes the late Holocene in the Southern Ocean. We targeted each of these features in sampling for 3He. Concentrations of 3He were converted to fluxes using the 230Th normalization method. To our

surprise, we found fluxes of 3He to be indistinguishable from the global average value at all times. In no case did we find evidence for increased melting of icebergs. This significant finding leads to a follow-up project to be performed during Year 5 of this work.

This work forms the Masters Degree research project for Shahla Ali.

Paleo-Ventilation
During the past year we have worked on several features of the climate-related changes in circulation of the Southern Ocean, specifically as these bear on the role of ocean circulation in abrupt climate change.

Detrital Strontium Isotopes in Cape Basin Sediments
Working with Randye Rutberg, an adjunct associate research scientist at Lamont, we have recently reinterpreted the record of carbon isotopic composition of benthic foraminifera found in sediments of the Cape Basin (SE Atlantic Ocean). Previous studies have interpreted the benthic carbon isotope records to reflect changes in the supply of North Atlantic Deep Water. However based on the high degree of correlation between the carbon isotope record and a high resolution record of the 87Sr/86Sr ratio of lithogenic phases in sediments of the Cape Basin, we have offered a new explanation for the carbon isotopes. Based on evidence that the detrital Sr record is forced primarily by the amount of lithogenic material delivered to the South Atlantic Ocean by the Patagonian Ice Sheet, we now interpret both the benthic carbon isotope record and the detrital Sr isotope record to reflect changes in the supply of Ice-Rafted Debris (IRD) from the Patagonian ice sheet to the South Atlantic Ocean. The IRD would have affected the Sr isotopes directly, and the carbon isotopes indirectly by supplying iron that fertilized phytoplankton growing in the region. Increased fluxes of carbon to the seabed associated with iron fertilization are inferred to have altered the carbon isotopic composition of the benthic foraminifera by changing the chemical composition of the microenvironments in which they grew. This work was recently published (Rutberg et al., 2005) and presented at the Spring 2005 AGU meeting.

Anderson's work on climate-related changes in the biological productivity of the Southern Ocean has also contributed to a synthesis paper on the role of the biological pump in regulating climate-related changes in the concentration of CO2 in the atmosphere (Kohfeld et al., 2005).

Highlights:

- Preliminary application of a new paleo proxy for ice berg melting found no evidence for surges of the Antarctic ice sheet in a sediment core from the northern Weddell Gyre
- New evidence links the carbon isotopic composition of benthic foraminifera in the deep Cape Basin (SE Atlantic) to surges in the Patagonian ice sheet rather than to abrupt changes in the formation of North Atlantic Deep Water
- Peaks in biological productivity in the vicinity of the Chatham Rise (near New Zealand) provide the first evidence for a manifestation of Heinrich Events in the Southern Ocean

Societal Benefits:

Understanding the scope and causes of past abrupt climate changes will help determine whether society is threatened by future abrupt climate change associated with global warming.

CICAR / NOAA Funded Research Connections:

Interagency and Research Partnerships:

Results form our recent NOAA-Funded work were used as supporting evidence in a collaborative proposal to the National Science Foundation, led by Dave Hodell, University of Florida. That proposal was funded, and we will be working with Hodell to search for evidence of surges in the Antarctic ice sheet during the last glacial period that may have been associated with abrupt climate changes.

Collaborators:

Our work with Julian Sachs (Massachusetts Institute of Technology) has produced multiple publications, most recently Sachs and Anderson (2005). See publications.

Our work with Anitra Ingalls (University of Washington) to develop a method for radiocarbon dating southern ocean sediments rich in biogenic opal but lacking in calcium carbonate that is normally used for dating) has led to one publication (Ingalls et al., 2004). In addition, Dr. Ingalls was recently (May, 2005) funded by the US NSF to continue the development of this method.

Awards/Honors:

Anderson was elected a Fellow of the AGU in 2005.
Anderson will receive the Huntsman Medal offered jointly by Dalhousie University and the Bedford Institute of Oceanography in September 2005.

Education and Outreach:

Academic Outreach:

Postsecondary:

Brenton Anderson, a qualified minority undergraduate, worked for Burkle as a summer student on this project in 2004 and 2005.

Research Advisor / Mentor:

Graduate:

Shahla Ali completed her Masters degree work under this project. She is now pursuing her Ph. D. Anderson serves as her academic and research advisor. Burckle serves on her research advisory committee.

Academic:

Symposiums:

Spring 2005 AGU Meeting – 2 presentations:

1. Anderson, R. F., M. Q. Fleisher and J. P. Sachs. Do geochemical proxy records in Cape Basin Sediments reflect changes in deep ocean circulation or surface productivity? Spring Meeting, American Geophysical Union, New Orleans.

2. Anderson, R. F., S. Ali, L. I. Bradtmiller, M. Q. Fleisher and C. Giulivi. Deglacial breakdown of ocean stratification - Evidence from the Ocean's Si Cycle. Spring Meeting, American Geophysical Union, New Orleans.

Personnel:

Research Scientist:	2
Research Support Staff:	2
Graduate Student:	1
Undergraduate Student:	1
Administrative:	2

Publications:

Journal Articles (submitted and in press):

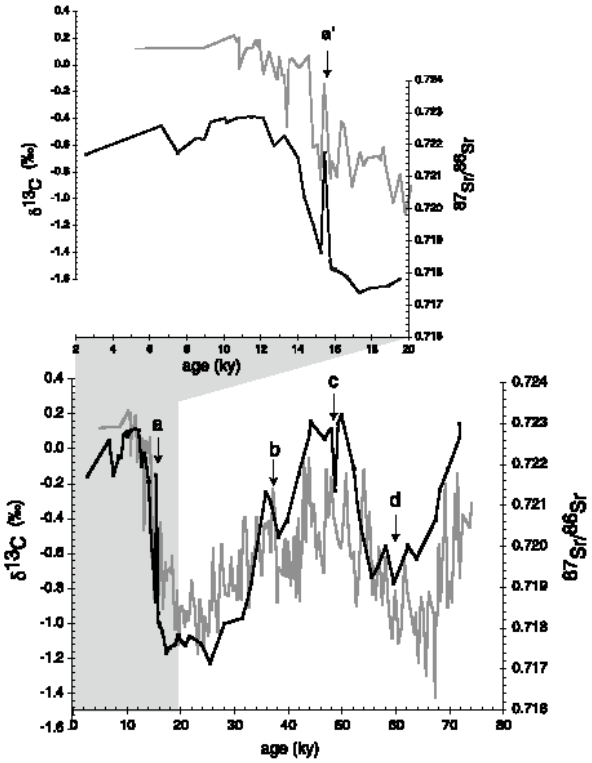
Ingalls, A. E., R. F. Anderson and A. Pearson (2004). Radiocarbon dating of diatom bound organic compounds. Marine Chemistry, 92, 91-105.

Rutberg, R. L., S. L. Goldstein, S. R. Hemming and R. F. Anderson (2005). Sr isotope evidence for sources of terrigenous sediment in the southeast Atlantic Ocean: Is there increased available Fe for enhanced glacial productivity? Paleoceanography, 20, PA1018, doi:10.1029/2003PA000999.

Kohfeld, K. E., C. Le Quéré, S. P. Harrison and R. F. Anderson (2005), Role of marine biology in glacial-interglacial CO2 cycles. Science, 238, 74-78.

Sachs, J. P., and R. F. Anderson (2005), Increased productivity in the subantarctic ocean during Heinrich Events. Nature, 434, 1118-1121.

ARCHES: Paleo Sea-Ice Distributions

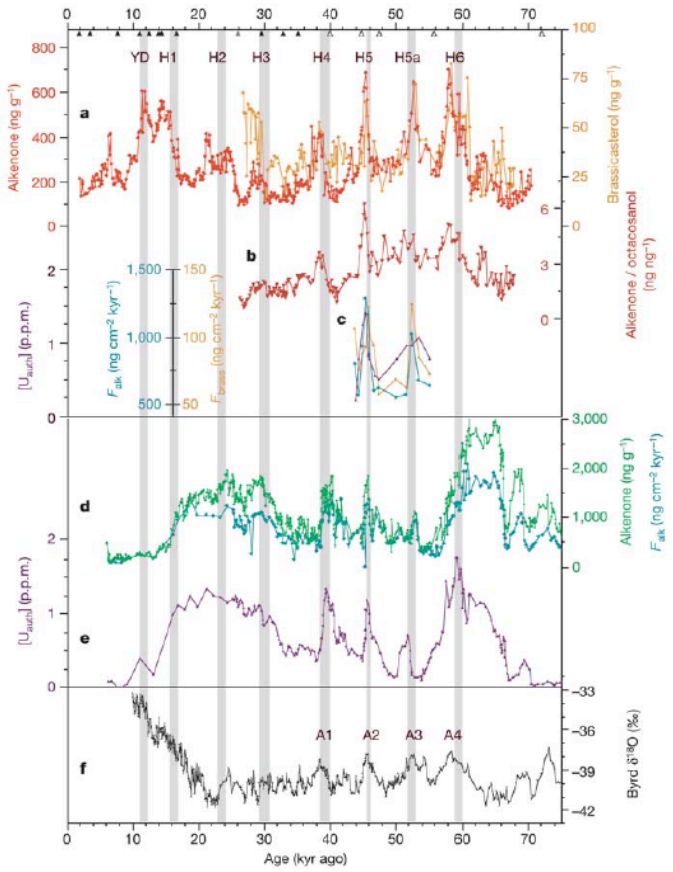


Detrital $^{87}Sr/^{86}Sr$ ratios (black line) and benthic d ^{13}C (gray line) plotted against age in core RC11-83 from the Cape Basin.

The arrows point to excursions in the 87Sr/86Sr (a–d) that visually correlate with excursions in the benthic d ^{13}C record. Features ‘‘a’’ and ‘‘a0’’ (inset) represents the abrupt, synchronous, excursion in both records that immediate precedes Termination 1.
The similarity of the two records is interpreted to reflect a common origin, inferred to be changes in delivery of lithogenic material to the South Atlantic Ocean by ice bergs shed from the Patagonian ice sheet.

From Rutberg et al., 2005.

Subantarctic Productivity Changes During Heinrich Events



(**a**) Alkenone (red) and brassicasterol (orange) concentrations in Chatham Rise core MD97-2120. Co-variation of these biomarkers for coccolithophorids and diatoms, respectively, indicates that algal productivity increased during HEs. (**b**) Ratio of alkenones to n-octacosanol in MD97-2120. An excess of algal lipids (alkenones) relative to terrestrial plant lipids (n-octacosanol) in H3-H6 implies that lipid preservation was not the primary cause of the algal biomarker concentration increases. (**c**) ^{230}Th-normalized flux of alkenones (teal) and brassicasterol (orange), and the concentration of authigenic uranium (U_{auth}; purple) in Chatham Rise core MD97-2120. (**d**) Alkenone concentration (green) and ^{230}Th-normalized alkenone flux (teal) in Cape Basin (Southeast Atlantic) core TN057-21-PC2. (**e**) The concentration of authigenic uranium in Cape Basin core TN057-21-PC2 (Sachs & Anderson, 2003; Sachs *et al.*, 2001). (**f**) d^{18}O variations, a proxy for air temperature, in the Byrd, Antarctica ice core. Prominent Antarctic temperature maxima A1-A4 coincide with Subantarctic productivity maxima and H4-H6. Age control points for MD97-2120 are shown at the top of panel **a**. Black triangles correspond to ^{14}C dates on the planktonic foraminifera *G. bulloides*, the grey triangle to the Kawakawa tephra, and open triangles to oxygen isotopic tie points to core MD95-2042 in the North Atlantic. Age control for TN057-21-2PC was provided by graphical comparison of magnetic intensity variations in the sediment with cosmogenic isotope production changes in Greenland ice.Calendar ages of the Heinrich Events are indicated by vertical gray bars, the thickness of which span their duration and age range from recent studies. From Sachs and Anderson, 2005.

Project Title: **ARCHES: Causes of Persistent Century-Scale Change in the North Atlantic's Holocene Climate**

Principal Investigator: Gerard C. Bond
Affiliation: Lamont-Doherty Earth Observatory

NOAA Program Manager: Dr. James Todd, CLIVAR Atlantic, 301-427-2089 Ext. 2383, james.todd@noaa.gov

Research Goals:

Identify abrupt climate change events in the Holocene and other interglacial period in data from ocean piston sediment record – focusing on the North Atlantic**;** Study the broader pattern North Atlantic events and their linkages of to other paleo-climate indicators

Research Progress:

Completed high-resolution Holocene records of Mg/Ca based surface temperature from planktic foraminifera at three sites located off Ireland and south and southeast of Iceland. The results demonstrate that temperatures fell about 1°C to 1.5°C during each peak in drift ice flux to the south, confirming the original interpretation that the petrologic indices of drift ice variations reflect ocean surface temperatures. These are rather large temperature changes for the Holocene in the North Atlantic, especially since they are from sites that lie in the warm North Atlantic Current.

The collaboration with AWI's Eduard Bauerfiend has continued and new sediment trap samples collected specifically for this project off the central Greenland coast demonstrated that in year 2002 two large sea ice melt events delivered thousands of sand-sized lithic grains to the sea floor. One occurred in April, the normal time of sea ice break up, releasing 40,000 grains/m2/0.5 months and the other occurred in late July-early August, the warmest months, releasing about 60,000 grains/m2/0.5 months. The data suggest that maximum delivery of sand-sized lithics to the sea floor from sea ice occurs during spring and summer in response to increasing temperature and sea ice breakup, and not during cold months when sea ice forms a continuous winter cover. In addition, around 20% of the sea ice-borne lithic grains are stained with hematite, suggesting that the Arctic is the ultimate source of the hematite-stained grain signal we have identified in the subpolar N. Atlantic and correlated with proxies of solar variability through the entire Holocene.

Confirmed a distinct trend in the subpolar North Atlantic spanning the last 4,000 years manifested as a steady cooling of the sea surface, based on our new Mg/Ca data, on an increase in IRD, and on an increase in production of NADW. We interpret the trends as a consequence of orbitally driven deterioration of high northern latitude climate causing a cooling of surface waters, which in turn undergo more vigorous convection and formation of NADW due to the temperature driven increase in density. The important implication in this case is that for moderate cooling the atmosphere drives deep ocean circulation. Records across the transition from the previous interglacial to the start of the last glacial appear to show the same patterns, suggesting that history may be repeating itself starting 4,000 years ago.

Began petrologic work on one of the cores, GGC53 in the eastern North Atlantic off Ireland where we obtained a high-resolution record of Mg/Ca ratios. This is a very high quality core with a sedimentation rate of 55 to 60 cm/ka. At 1 cm resolution (about 50 years), we found that in a selected interval, the millennial variations documented in earlier work are composed of robust bundles of ~ 500 year cycles. These cycles demonstrate a good match to 500-year cycles in the tree ring record of atmospheric radiocarbon (see figure below), that are taken by most as dominantly solar in origin. This is very encouraging evidence strongly supporting the importance of a sun-climate connection in the North Atlantic.

Highlights:

- Confirmed that the petrologic indices of drift ice variations in the North Atlantic during the Holocene, reflect large (1-1.5°C) changes in ocean surface temperature.
- Sediment trap data near Greenland confirm that large sea-ice melting events deliver sand-size lithic grains to the sea floor with maximum delivery occurring spring ans summer giving clues to the nature of millennial events that occurred during the Holocene.
- The moderate cooling of the atmosphere in the last 4000 years has been driving more NADW production through lowering the surface temperature and increasing density.

Societal Benefits:

Develop understanding of abrupt climate change events. Identify abrupt changes in the Holocene – an interglacial period.

CICAR / NOAA Funded Research Connections:

Research Partnerships:

This work is part of the CORC/ARCHES project

Collaborators:

Eduard Bauerfiend (AWI)

Personnel:

Research Scientist: 1
Research Support Staff: 1
Administrative: 1

Publications:

Journal Articles (submitted and in press):

Andersen, C., G. Bond, A. Kuijjpers, P. Knutz, and S. Bjorck, S., 2005: Holocene climate variability at multidecadal time scales detected by sedimentological indicators in a shelf core NW off Iceland, *Marine Geology*, **214**, p. 323-338.

Müller, U. C., S. Klotz, M. A. Geyh, J. Pross, G. C. Bond, Cyclic climate changes during the Eemian interglacial in central Europe, *Geology*, in press.

Books / Articles-in-Books:

Almasi, P. and G. Bond, Sun-climate connections, Encyclopedia of Paleoclimatology and Ancient Environments, Earth Science Series, Kulwer Academic Publishers, Dordrecht, the Netherlands. In press.

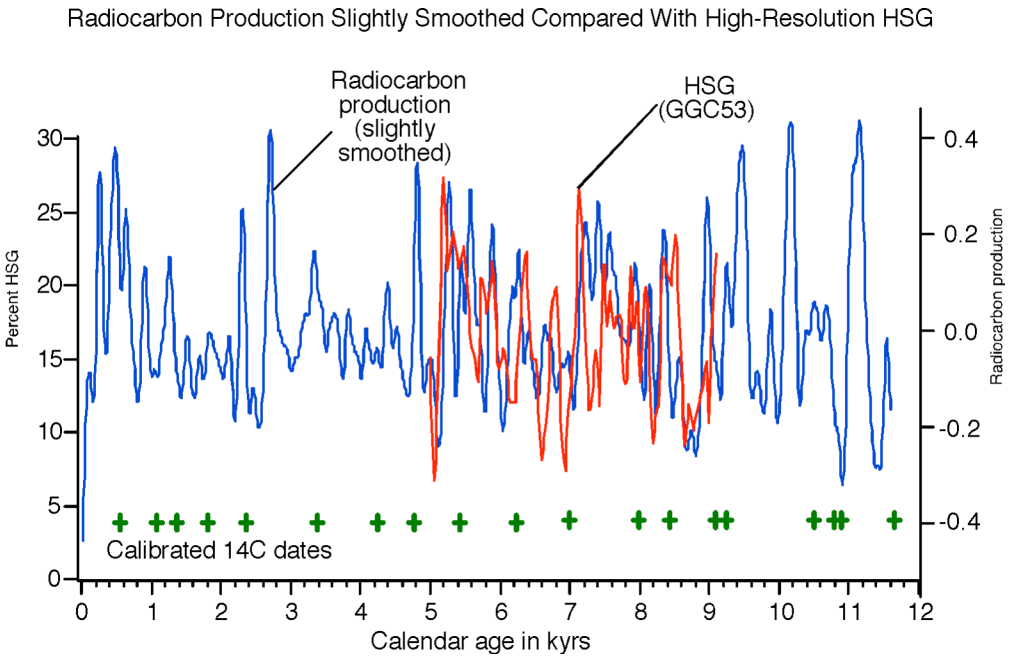
Bond, G., Climate variability and cycles, millennial, Encyclopedia of Paleoclimatology and Ancient Environments, Earth Science Series, Kulwer Academic Publishers, Dordrecht, the Netherlands. In press

Bond, G., The interactions of glaciers and oceans in the context of changing climate, in P. Knight ed. Glaciology and Earth's Changing Environment, Blackwell Publishing, Oxford, UK. In press.

Reports:

Bond G., Radiative Forcing of Climate Change: Expanding the Concept and Addressing Uncertainties, Report of the National Research Council of the National Academy of Sciences, The National Academies Press, Washington, D.C. (contributing member of Committee on Radiative Forcing Effects of Climate), in press.

ARCHES: Causes of Persistent Century-Scale Change in the North Atlantic's Holocene Climate



Comparison Of Slightly Smoothed Tree Ring Radiocarbon With New Petrologic Measurements In Eastern North Atlantic Core GGC53 With Sedimentation Rates Of 55 To 60 Cm/Ka

The results show a close match between the atmospheric radiocarbon and the drift ice index hematite stained grains in robust 500-year cycles. Up pointing peaks in radiocarbon indicate a weaker sun; up pointing peaks in HSG indicate more drift ice and cooler ocean surface temperatures (by about 1°C to 1.5°C).

Project Title: **ARCHES: Understanding Abrupt Change and the Glacial to Interglacial CO_2 Record**

Principal Investigator: Wallace Broecker
Affiliation: Lamont-Doherty Earth Observatory

NOAA Program Manager: Dr. James Todd, CLIVAR Atlantic, 301-427-2089 Ext. 2383, james.todd@noaa.gov

Research Goals:

To understand how ocean circulation has changed over the last 20,000 years and how these changes have impacted climate.

Education Goals:

W.S. Broecker has put considerable effort into making a road map for carbon management. This includes a document entitled *A Business Executive's Guide to Global Warming*.

Research Progress:

During year two of Arches, progress was made in the following areas: 1) We continued our quest to understand the cause for radiocarbon-age differences between coexisting planktic foraminifera shells. A break-through came when shells from a layer in a high accumulation-rate deep-sea core from the Morotai Basin just south of the Philippine Island of Mindanao yielded ages for the robust species *P. obliquiloculata* 4 kyrs older than those for the fragile species *G. sacculifer*. As both of these ages fell well above the age versus depth in core plot established for other samples, which yielded concordant planktic ages, we had proof that the anomalies were the result of the incorporation of reworked material. Now we know that we must analyze robust-fragile pairs in order to validate the absence of reworked material. A paper entitled "Anomalous radiocarbon ages for foraminifera shells" has been completed and will be submitted soon. 2) We seek to understand the well-documented 190 per mil drop in the ^{14}C to C ratio of atmosphere and surface ocean CO_2 during the period 17.5 to 14.5 kyrs (i.e. the time interval between Heinrich event #1 and the onset of the Bolling-Allerod). By the process of elimination, the major part of this drop must be the result of the mixing between an isolated radiocarbon deficient glacial abyssal ocean and upper ocean. However, we are having difficulty reconciling the large size required for this reservoir with radiocarbon-based (i.e., benthic-planktic age differences) and ^{13}C to ^{12}C ratios in glacial-age benthic foraminifera. A paper has been prepared on this subject for presentation at the September 6, 2005 Accelerator Mass Spectrometry Conference in Berkeley, California. 3) We proposed at a recent Chapman Conference held at Woods Hole that the numerous $CaCO_3$ dissolution indices being employed to reconstruct past deep ocean carbonate ion concentrations be compared one with another. As phase one of this exercise, we proposed that the Holocene sections of a series of box cores taken on the equator in the western Pacific Ocean be studied. Core-top samples from a series of water depths would provide a calibration of each method. Down core measurements of the deeper cores would provide a measure of the carbonate ion decrease over the last 8000 years. We have used the size index and the shell weight measurements to show that this pilot study will be productive.

Highlights:

- Ventilation of the deep sea during glacial time.
- Events associated with the "Mystery Interval" (17.5 to 14.5 kyrs).
- The rise in atmospheric CO_2 over the last 8000 years.

Societal Benefits:

Publicizing the need to quell CO_2 emissions and how this might be done economically.

CICAR / NOAA Funded Research Connections:

Interagency:

Cosponsoring with National Science Foundation

Research Partnerships:

ETH in Zurich, Switzerland

Collaborators:

John Hayes, Woods Hole Oceanographic Institution, Irena Hajdas, ETH, Zurich, Switzerland, Lowell Stott, University of Southern California.

Education and Outreach:

Academic Outreach:

K-12:

Summer high school students

Postsecondary:

Graduate – Comer Fellowship program

Research Advisor / Mentor:

Graduate:

Allison Franzese, Greg Downing, Susan Zimmerman

Presentations:

W. Broecker, “Climate Flickers" workshop at Lamont, June 9-10, 2005

Fellowship Programs / Internships:

Mentor for Post Doctoral Fellow Stephen Barker

Databases:

http://www.ldeo.columbia.edu/users/broecker/data.html.

Personnel:

Research Scientist: 1
Research Support Staff: 1
Administrative: 1
Post Doctoral Fellow: 1

Publications:

Journal Articles (submitted and in press):

W.S. Broecker, S. Barker, E. Clark, I. Hajdas, and G. Bonani, Anomalous radiocarbon ages for foraminifera shells, *Paleoceanography*, submitted August 29, 2005

Books / Articles-in-Books:

W.S. Broecker**,** *The Role of the Ocean in Climate, Yesterday, Today and Tomorrow*, Eldigio Press, NY, 2005.

Reports:

W.S. Broecker, S. Barker, and E. Clark, Calibrating dissolution indices, Chapman Conference, Woods Hole Oceanographic Institution, 2005.

Project Title:	**ARCHES Lamont-Doherty Sub-Awardee: Mountain Snowlines in the Southern Hemisphere**
Principal Investigator:	George Denton
Affiliation:	University of Maine, Quaternary & Climate Studies
NOAA Program Manager:	Dr. James Todd, CLIVAR Atlantic, 301-427-2089 Ext. 2383, james.todd@noaa.gov

Research Goals:

The research objectives were accomplished as outlined in the proposal with one major exception. Field work in the Rakaia Valley and map digitizing had to be postponed until the 2006 austral summer field season; this delay occurred because David Barrell, our New Zealand colleague, had to drop out of the project temporarily when a close family member became seriously ill. I requested a no-cost extension and will finish the Rakaia Valley fieldwork with David Barrell and B.G. Andersen in the first half of 2006. This places a heavy burden on fieldwork during the coming austral summer and may require two trips to New Zealand, with the field work split into two sessions.

- The overall goal of the project for the past year was to reconstruct snowline changes in the Southern Alps of New Zealand during the last glacial cycle. New Zealand is situated in the zone of mid-latitude Southern Hemisphere westerlies in the South Pacific Ocean far from any major continental influences or zones of thermohaline downwelling. Also, New Zealand is on the opposite side of the planet (and with an opposite insolation signal) from the North Atlantic region, which has produced the classic record of abrupt climate changes. The idea is that a comparison of New Zealand snowline variations with the North Atlantic abrupt-change records will point to some of the underlying mechanisms.
- The major research activities involved mapping in New Zealand's Southern Alps in 2004/2005, together with office work during the rest of the year on map digitizing, air-photograph interpretation, and snowline reconstruction from field data. The collaborators in the field were Björn G. Andersen of the University of Oslo, Christian Schlüchter of the University of Bern, Marcus Vandergoes of the University of Maine, and David Barrell of the Crown Institute of Geologic and Nuclear Sciences (IGNS) in New Zealand. B.G. Andersen also carried out the interpretation of air photographs. David Barrell supervised the digitizing of glacial geologic maps at IGNS Dunedin, New Zealand. Trevor Chinn, Alpine and Polar Processes Consultancy, Wanaka, New Zealand, carried out the snowline studies.

Research Progress and Highlights:

The following was accomplished in Year 4. Note that Year 4 research is still in progress, for which a no-cost extension has been requested.

1. A huge, detailed, second-generation map of the LGM moraines near Lake Pukaki has been completed as background for a drilling program in Lake Pukaki itself and for the exposure-dating program proposed here for Year 5.
2. The mapping of LGM, late-glacial, and Holocene moraines has been completed in the Ben Ohau and Liebig Ranges on the eastern flank of the Southern Alps. Snowline calculations have been made for moraines in each of the valleys of these two ranges. They show snowline lowerings below today's values of 670-725 m for the outer LGM moraines, 447 for the outer late-glacial moraines, 168 m for the A.D. 1860 moraine and 360 m for the outermost Holocene moraines.
3. Twenty new radiocarbon ages were processed for bark from well-preserved pieces of wood from the lee of Canavans Knob, where they were pushed during the late-glacial advance of Franz Josef Glacier. Fourteen of the original 17 dates gave values in excess of 11,000 ^{14}C yr B.P. A redating of the other three samples also yielded values greater than 11,000 ^{14}C yr B.P. the second time around. This result suggests strongly that the late-glacial

readvance in New Zealand peaked just before the beginning of the classic Younger Dryas cold reversal in the North Atlantic region. A similar result had already been attained for the classic Punta Bandera late-glacial moraines at Lago Argentino in Patagonia. I now think that this late-glacial readvance most likely represents the culmination of the Antarctic Cold Reversal.

4. Mapping and radiocarbon dating were carried out on LGM moraines and outwash plains near Murchison in the northern part of the Southern Alps.
5. Four cores were collected from Galway Tarn on the west side of the Southern Alps. The purpose was to obtain accurate radiocarbon dates for a prominent volcanic ash that occurs in all the LGM moraine sequences.

Publications:

Journal Articles (submitted and in press):

Denton, G.H., Alley, R., Comer, G.S., and Broecker, W.S., 2005, The role of seasonality in abrupt climate change. Quaternary Science Reviews, 24, 1159-182.

Denton, G.H., Moreno, H., and Moreno, P.I., 2004, Deglacial chronology of the northern
Chilean Lake District from radiocarbon dates of the Licán pyroclastic flow. Sernageomin Villarica Bulletins published.

Preusser, F., Andersen, B.G., Denton, G.H., and Schlüchter, C., 2005, Luminescence chronology of Late Pleistocene glacial deposits in North Westland, New Zealand. Quaternary Science Reviews, in press.

Strelin, J., and Denton, G.H., 2005, Las Morenas de Puerto Bandera, Lago Argentino. XVI Argentine Geological Congress, v. in press and online at QSR.

Project Title:	**Lamont-Doherty Earth Observatory Sub-Awardee for ARCHES: Accelerator Mass Spectrometric Analyses of RadioCarbon**
Principal Investigator:	John Hayes
Affiliation:	Woods Hole Oceanographic Institution
NOAA Program Manager:	Dr. James Todd, CLIVAR Atlantic NOAA/OGP, 301-427-2089 Ext. 2383, james.todd@noaa.gov

Progress Report:

Accelerator Mass Spectrometric Analyses of Radiocarbon, John M. Hayes,
PI on behalf of the National Ocean Sciences Accelerator Mass Spectrometry Facility, Woods Hole Oceanographic Institution. Funds awarded: $62,107 for 1 January 2001 – 31 December 2003, $20,491 for 1 January 2004 – 31 December 2004.

During the reporting period 1 January 2004 – 31 December 2004 fees totaled $20,446 in support of 68 analyses of radiocarbon for ARCHES investigators (Bond, 52 samples; Denton, 15;
Anderson, 1). Of these, 15 were analyses of 14C in organic carbon and 53 were analyses of carbonate minerals. A balance of $45 remains for analyses to be completed after 31 December 2004. Turnaround times are presently averaging 8-10 weeks.

Project Title:	**ARCHES: Constraining Changes in Winds, the Conveyor and Local Currents During Periods of Abrupt Climate Change**
Principal Investigator:	Sydney Hemming
Affiliation:	Lamont-Doherty Earth Observatory
NOAA Program Manager:	Dr. James Todd, CLIVAR Atlantic NOAA/OGP, 301-427-2089 Ext. 2383, james.todd@noaa.gov

Research Goals:

Funding from ARCHES/CICAR has aided our endeavors in several projects of relevance to rapid climate change. One goal is to study sediment composition and flux of samples along the mid-Atlantic ridge (MAR) to constrain the processes responsible for the distribution, and in the most exciting case, to constrain the position of the ITCZ. This contributes towards our long-term goal to have a map of LGM terrigenous isotope composition for the South Atlantic that is comparable to the Holocene map that exists now. A further goal is continued method development, both for the authigenic ferromanganese and terrigenous detritus components. As mentioned in the year 3-progress report, we have found that not all cores give true marine signals as monitored by the Sr isotope composition of the ferromanganese fraction. We have still not yet solved the problem and will continue the work in year 5. A major shift in the goal for year 4 was a return to the North Atlantic to study high-resolution ocean-atmosphere-ice sheet interaction as well as to characterize major ice rafted detritus (IRD) contributors in the North Atlantic region.

Education Goals:

This funding has also enhanced our ability to contribute to the educational development of students and postdoctoral scientists. The specific goal of the June 04-June 05 interval was to introduce post doctoral research scientist, Martin Roy, to the application of radiogenic isotope tracers in paleoclimate studies- in other words to expand his research tool kit. Roy received his Ph.D. in Glacial Geology, and is naturally interested in extending his understanding of tracing sediment sources. Additionally, Liz Knapp, a Tappan Zee High School student, is working with us on a study of North Atlantic rapid climate/ice sheet variability. And finally, although her salary is supported by an NSF fellowship, graduate student Allison Franzese's research has benefited from our ARCHES/CICAR funding. Our educational goals are thus best characterized as integration of research and education and discovery based learning. Both Franzese and Roy have mentored more junior scientists, an experience that benefited them as well as their student research helpers.

Research Progress:

We have made good progress towards our objectives in this interval. During year 4, we completed a study along the Mid-Atlantic Ridge (MAR), with particular emphasis on sedimentary processes near the equator (Allison Franzese presented at the ICP8 conference in Biarritz France). Additionally, Allison Franzese has made progress towards identifying LGM horizons, a prerequisite for this goal, and has presented at the fall 2004 AGU a paper that addresses the role of the Agulhas Current in Cape Basin sediment compositions (Franzese et al., in prep.).

A further goal is continued method development, both for the authigenic ferromanganese and terrigenous detritus components. As mentioned in the year 3-progress report, we have found that not all cores give true marine signals as monitored by the Sr isotope composition of the ferromanganese fraction. We have still not yet solved the problem and will continue the work in year 5. However, the cores from the southern Cape Basin have yielded really exciting results and Alex Piotrowski published two papers on the application of the authigenic ferromanganese

component from the Cape Basin (Piotrowski et al., 2004, 2005) and is in the process of preparing a paper that presents a survey of Holocene and LGM values in the South Atlantic (Piotrowski et al., in prep.). Additionally, various aspects of these data were reported in two abstracts at the ICP8 meeting in Biarritz by Steve Goldstein (invited talk) and Alex Piotrowski, as well as in three abstracts at the fall 2004 AGU by Steve Goldstein, Sidney Hemming, and Alex Piotrowski, and one at the spring 2005 AGU (first author Piotrowski).

Sidney Hemming and Martin Roy joined Ian Hall on a cruise from Lisbon Portugal to Cardiff Wales, on the Marion Dufresne in the summer of 2004 to collect a companion core to DAPC2 in the Rockall Trough where Ian Hall, Paul Knutz and colleagues have produced a high-resolution climate record (including IRD counts). We collected an approximately 7-meter casque core that should extend through the last glacial cycle, to almost Stage 5. Additionally, we collected a long piston core from this site that will almost certainly penetrate Stage 6. Hall has received funding from NERC to obtain radiocarbon results on the casque core, and we will contribute to the sediment processing and foraminifera picking for this goal. In Wales we collected some tills from the Gower Peninsula to make isotopic measurements for comparison to ocean samples.

We produced $^{40}Ar/^{39}Ar$ measurements on a series of till samples along the 58^{th} parallel from Hudson Bay to the Labrador Sea as part of our goal of characterizing potential ice rafted detritus contributors around the North Atlantic. Martin Roy is in the process of compiling and interpreting these data, and plans to present the results at the fall 2005 AGU.

We also made a study of $^{40}Ar/^{39}Ar$ ages of detrital hornblende grains in ODP984, just south of Iceland that seems to show a substantial contribution from southern Norway. It is really important to document the contributions of different ice sheets around the North Atlantic and our growing collaborations with European colleagues are greatly facilitating this goal. Sidney Hemming presented these results at the spring 2005 AGU.

We contributed to high-resolution studies of two North Atlantic sediment cores (Julien et al., submitted; Peck et al., submitted., as well as abstracts presented at the spring 2004 AGU, ICP8, and EGU meetings), and also made contacts on the cruise that will lead to further collaborations that include IRD provenance studies.

Highlights:

- authigenic ferromanganese oxide-hosted Nd isotopes give high-resolution picture of deep Atlantic ocean circulation over the past 90 kyrs.
- sediment distributions and fluxes in the equatorial Atlantic yield insights into surface and deep ocean dynamics, and may help constrain the paleo-ITCZ
- high resolution studies of ice rafting, coupled with multiple proxies of sea surface conditions and ocean circulation, yield important insights into ice sheet contributions to rapid climate variability in the last glacial cycle

Societal Benefits:

As we continue to modify our atmosphere with anthropogenic emissions, it becomes more an more relevant to better understand the mechanisms of global and rapid climate variability. All of our goals are motivated by the need to characterize the ocean-atmosphere-ice sheet interactions of the past

CICAR / NOAA Funded Research Connections:

Interagency:

Funding for the MAR work is partly from NSF. As mentioned above, Allison Franzese has an NSF Fellowship. Additionally, Goldstein, Hemming, Anderson and Ninnemman had an NSF-OCE grant to use multiple proxies to test whether there have been changes in the Agulhas leakage in the last glacial, and Goldstein and Hemming have recently been funded for further ground-truthing of the authigenic and terrigenous

components in the Natal Valley which will allow better constraints on the Agulhas Current as well as the contribution of North Atlantic Deep water in the glacial.

Collaborators:

This funding has allowed us to initiate several research projects in collaboration with Ian Hall (Cardiff University). Additionally, we have benefited by association with others in the consortium

Awards/Honors:

Alex Piotrowski was selected for a student poster prize at the ICP8 meeting in Biarritz France Sept 2004

Education and Outreach:

Academic Outreach:

K-12:

We have hosted several high school students from the Lamont area to participate in our research projects of this grant.

Research Advisor / Mentor:

Undergraduate:

Sean Culkin did a summer intern project in 2004, supervised by Allison Franzese. He went on to finish his degree from Johns Hopkins in the spring of 2005, and he is beginning graduate school at Penn State this fall. Stephanie Pahler is entering her senior year at Barnard College. She is working with Allison Franzese and Sidney Hemming on sediment provenance in the equatorial Atlantic for her senior thesis project. She was an intern in the REU program in the summer of 2005.

Graduate:

Allison Franzese is a senior graduate student (advisor Sidney Hemming) who is working on using geochemical tracers of terrigenous sediments to constrain past ocean-atmosphere dynamics. Kevin Jones is a junior graduate student (advisor Steve Goldstein) who is using geochemical tracers to isolate the wind-derived sediments from marine cores.

Presentations:

Allison Franzese presented her research to the REU summer intern program in June 2005 at LDEO on the application of terrigenous provenance to constrain changes in the Agulhas Retroflection

Personnel:

Research Scientist:	1
Post Doctoral Fellow:	2
Graduate Student:	2

Publications:

Journal Articles (submitted and in press):

Julien, E., Grousset, F. E., Hemming, S. R., Peck, V. L., Hall, I. R., and Jeantet, C., submitted, Contrasting conditions preceding MIS3 and MIS2 Heinrich events, submitted to a special volume.

Peck, V. L., Hall, I. R., Zahn, R., Elderfield, H., Grousset, F. E., Hemming, S. R., and Scource, J. D., submitted, High resolution evidence for linkages between European ice sheet instability and deep North Atlantic circulation, Earth and Planetary Science Letters.

Piotrowski, A.M., Goldstein, S.L., Hemming, S.R. and Fairbanks, R.G., 2004, Intensity and variability of ocean thermohaline circulation during the last deglaciation, Earth and Planetary Science Letters, 225: 205-220.

Piotrowski, A.M., Goldstein, S.L., Hemming, S.R., and Fairbanks, R.G., 2005, Temporal relationships of carbon cycling and ocean circulation at glacial boundaries, Science, 307, 1933-1938.

Rutberg, R.L., Goldstein, S.L., Hemming, S.R., and Anderson, R.F., 2005, Sr isotope evidence for sources of terrigenous sediments in the southeast Atlantic Ocean: is there increased available Fe for enhanced glacial productivity?, Paleoceanography, v. 20, doi: 10.1029/2003PA000999

Conference Proceedings / Workshops:

Culkin, S. and Franzese, A., 2004, Distinguishing Between Provenance Changes and Sorting Effects on the Rb-Sr Systematics in Glacial and Holocene South Atlantic Sediments, Eos Trans. AGU, 85(47), Fall Meet. Suppl., Abstract PP33A-0908.

Franzese, A. M., Broecker, W. S., Hemming, S. R., and Anderson, R. F., 2004, Carbonate sedimentation on the mid-Atlantic ridge since the last glacial maximum, Eights International Conference on Paleoceanography (ICP-8), Biarritz, France, 2004.

Franzese, A.M., Hemming, S.R., Goldstein, S.L., Anderson, R.F., and Broecker, W.S., "Glacial-interglacial changes in the provenance and flux of sediment to the Cape Basin, South Atlantic: implications for Indian-Atlantic ocean exchange", Fall 2004 AGU Meeting.

Hemming, S.R., Goldstein, S.L., Piotrowski, A.M., Franzese, A.M., Broecker, W.S., and Curry, W.B., "Glacial Nd isotope composition of Equatorial Atlantic Bottom Water", Fall 2004 AGU Meeting.

Hemming, S. R., Downing, G. E., and McManus, J. F., 2005, Ar-Ar Evidence for Provenance of Ice-rafted Hornblende Grains from ODP site 984, Eos Trans. AGU, 86(18), Spring Meet. Suppl., Abstract PP23A-04.

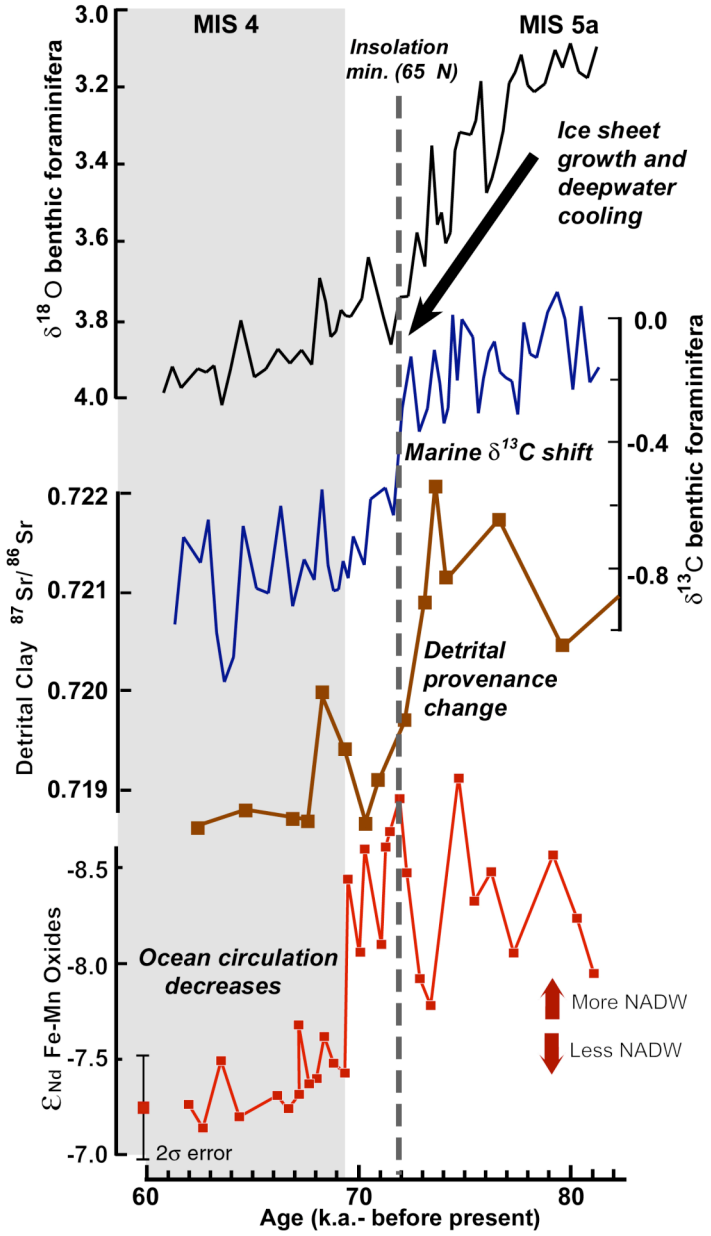
Goldstein, S.L., Piotrowski, A.M., Hemming, S.R., Fairbanks, R.G., and Zylberberg, D. "A record of the global overturning circulation over the past 100 ky", Eighth International Conference on Paleoceanography (ICP-8), Biarritz, France, 2004 (Plenary presentation).

Goldstein, S.L., Piotrowski, A.M., Hemming, S.R., Fairbanks, R.G., and Zylberberg, D. "A record of the global overturning circulation over the past 100 ky", Fall 2004 AGU Meeting (Invited).

Piotrowski, A.M., Goldstein, S.L., and Hemming, S.R. "Ocean circulation and carbon cycling relationships during glacial-interglacial transitions", Eighth International Conference on Paleoceanography (ICP-8), Biarritz, France, September 2004

Piotrowski, A.M., Goldstein, S.L., and Hemming, S.R. "Stratification and circulation of the glacial ocean: reconstructing watermass geometry and circulation with Nd isotopes" Fall 2004 AGU Meeting.

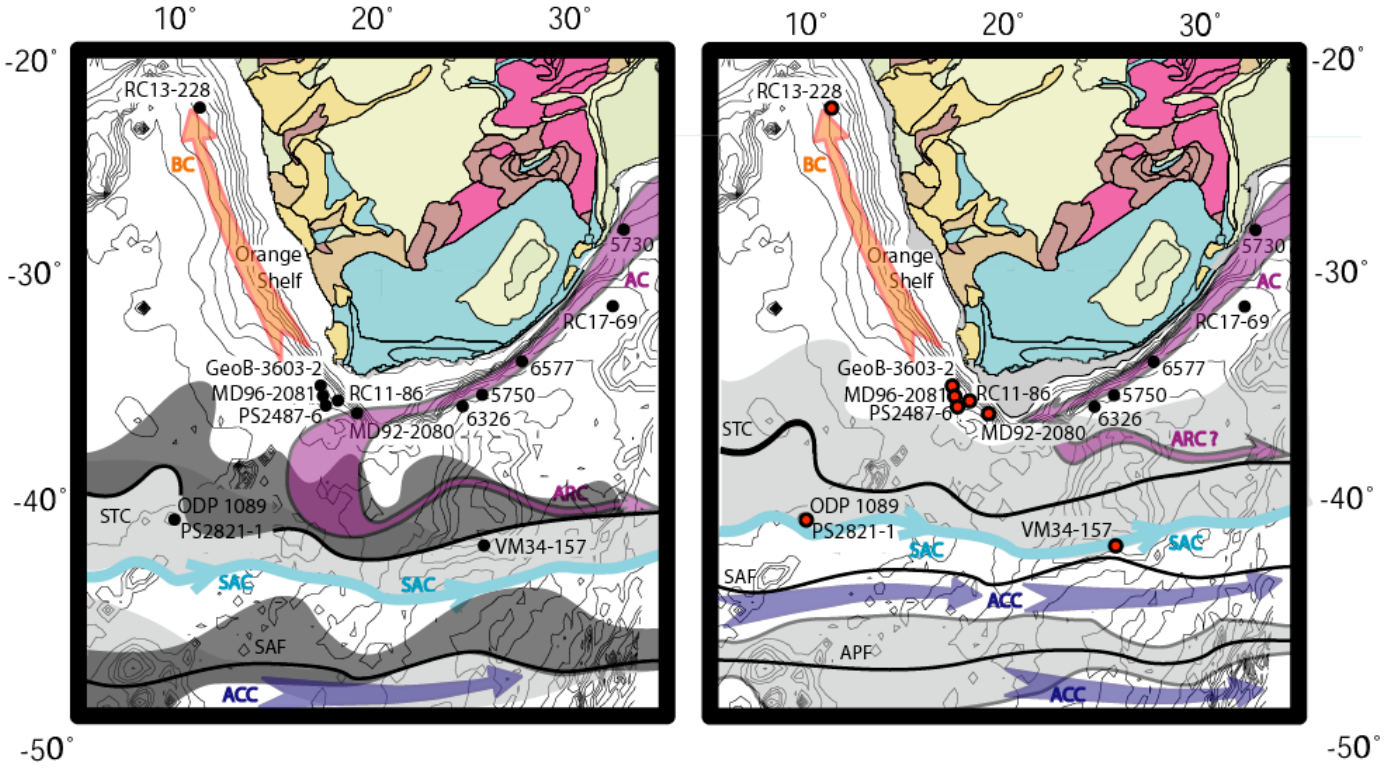
ARCHES: Constraining Changes in Winds, the Conveyor and Local Currents During Periods of Abrupt Climate Change



Sequence Of Events At The Start Of The Last Ice Age (Piotrowski Et Al., 2005)

The $\delta^{18}O$ of benthic foraminifera changed first, indicating ice sheet growth and deep water cooling. This is followed by a shift in the $\delta^{13}C$ of benthic foraminifera (same samples), indicating a combined change in circulation and/or carbon storage in the ocean. The terrigenous detrital composition changes after the shift in $\delta^{13}C$, and indicates a change in local current movements (difficult to distinguish surface and deep in this setting, but the non-synchronous change in the terrigenous Sr and authigenic Nd is an important test of the interpretation of the authigenic Nd). Finally, the authigenic Nd, best interpreted as a deep circulation tracer, changes. This is taken to provide important constraints on the role of deep ocean circulation in driving climate change and most simply implies that deep ocean circulation responded to initiation of the ice age, but reduced circulation did not trigger i.

ARCHES: Constraining Changes in Winds, the Conveyor and Local Currents During Periods of Abrupt Climate Change



Compilation Of Modern (Left) And Last Glacial Maximum (Right) Evidence For The Position Of The Agulhas Retroflection (From Allison Franzese)
The marked cores are where studies have been published with conclusions that bear on this question. The conclusion from the study of Allison Franzese, consistent with published results, is that the Agulhas Leakage was never completely shut off from the Atlantic Ocean. However, it appears likely that the Agulhas Retroflection may have shifted northward and possibly eastward in the LGM relative to the modern. The contrasting geological terrains of the region yield the possibility of constraining this better with more detailed mapping of provenance (ongoing). BC= Benguela Current, STC= Subtropical Convergence, SAC= South Atlantic Current, SAF= Sub-Antarctic Front, ACC= Antarctic Circum-polar Current. AC= Agulhas Current, ARC= Aguhas Return Current (or retroflection).

Project Title: **ARCHES: Patterns and Timing of Deglacial Climate Change in the Equatorial Pacific**

Principal Investigator: Jean Lynch-Stieglitz
Affiliation: Lamont-Doherty Earth Observatory / Adjunct Research Scientist

NOAA Program Manager: Dr. James Todd, CLIVAR Atlantic NOAA/OGP, 301-427-2089 Ext. 2383, james.todd@noaa.gov

Research Goals:

To characterize and understand the modes and mechanisms of equatorial Pacific ocean-atmosphere coupling during glacial-interglacial transitions, particularly as they relate to variability in the eastern Pacific cold tongue-Intertropical Convergence Zone and associated oceanographic front. The strategy has been to measure Mg/Ca and $\delta^{18}O$ of planktonic foraminifera in a north south transect of cores between 2 South and 7 North, and use them as proxies of the oceanographic front and its temporal variability.

Research Progress:

In 2004-05 our work focused mostly on site V28-134 (6.9ºN, 85.4ºW, 2434 m), our northernmost site, thus extending our transect of cores northward to the approximate mean latitude of the ITCZ (7-8º N). Two $\delta^{18}O$ profiles were produced from this core, on the planktonic foraminifera *G. ruber* and *G. sacculifer*. In addition we generated a Mg/Ca SST reconstruction on the *G. ruber* species from the same core. A total of 18 new radiocarbon ages were also produced to establish and refine the age models from V28-134 and other cores in the meridional transect across the equator (RC12-27, V21-30, V19-28).

These new data have now extended and consolidated our previous results (*Koutavas and Lynch-Stieglitz,* 2003) which indicated a weakening of the equatorial front in the Last Glacial Maximum
(LGM) in comparison with the Holocene, interpreted to reflect a glacial shift of the ITCZ to the south and a weakening of the upwelling cold tongue. The new data from V28-134 now allow us to make a much more confident quantitative assessment of the magnitude of this change.

The Holocene $\delta^{18}O$ data from both V21-30 and V28-134 are in excellent agreement with predicted values from modern temperature and salinity, which demonstrates that the $\delta^{18}O$ is faithfully recording mean surface hydrography and bears no detectable artifacts due to dissolution. More specifically, the average Holocene gradient in $\delta^{18}O$ between V21-30 (1.2 ºS) and V28-134 (6.9º N) is calculated to be 1.2 ‰, which accurately reflects the modern SST and salinity gradient between the two sites (4º C and 1 psu, respectively). By comparison, the average $\delta^{18}O$ gradient during the LGM (18-24 ky) is calculated to be only 0.8 ‰, thus reflecting a 50% increase from the LGM to the Holocene. To put these values in perspective we note that in today's climate a transition from an El Nino year to a La Nina year is accompanied by a doubling (100% increase) of the temperature/salinity gradient between the two sites. Thus the glacial-interglacial change appears to be equivalent to one-half of that produced today interannually due to ENSO, which represents a very significant change.

In this light the results provide unambiguous constraints on the glacial-interglacial pattern of variation of the Pacific cold tongue-ITCZ front. They strengthen the assertion that atmospheric forcing of the equatorial Pacific cold tongue through extratropical modulation of the ITCZ position is an important and perhaps dominant aspect of the dynamical adjustment of the ocean-atmosphere system during glacial cycles.

Highlights:

- Weakened equatorial front during the LGM
- Southward shift of the Pacific ITCZ during the LGM

- Average LGM cooling of the equatorial cold tongue of ~2 ºC

Societal Benefits:

The response of the tropical Pacific and the ENSO system to future climate change is an issue of great societal significance but remains subject to large uncertainty. The long-term dynamics of this system and its susceptibility to future change can best be understood by reconstructing its past variability and its links with past global climate states. Our research demonstrates a clear link between variability in the ITCZ (likely driven by extratropical forcing), and in tropical Pacific SSTs and SST gradients on glacial-interglacial timescales. In conjunction with other studies, our results show that this link operates on a spectrum of timescales, from the interannual to the orbital range, and therefore is relevant for how the tropical Pacific ocean-atmosphere system will respond to climatic warming in coming decades. More specifically our results caution that a possible shift of the ITCZ to the north due to differential warming of the hemispheres can lead to a strengthening of tropical SST gradients and of the Walker circulation with significant climatic and hydrologic impacts in North America and around the world.

CICAR / NOAA Funded Research Connections:

Interagency:

This work has complemented and benefited an NSF -funded project in the same region (NSF award OCE-04-02478, Peter B deMenocal and Athanasios Koutavas, PIs)

Collaborators:

Peter B. deMenocal, Lowell D. Stott, John C. H. Chiang

Awards/Honors:

2004 American Geophysical Union Editor's Citation for Excellence in Refereeing for *Paleoceanography*, presented to Athanasios Koutavas

First Place Poster Competition, Paleoclimate Modeling Intercomparison Project-2 Workshop, Giens, France 2005, Title: "Tropical Pacific SST gradients during the LGM and links with the ITCZ", presented by Athanasios Koutavas.

Education and Outreach:

Academic Outreach:

Postsecondary:

Parts of this research were incorporated in the teaching of "Frontiers of Science", a newly instituted undergraduate course as part of Columbia University's Core Curriculum (Athanasios Koutavas, co-instructor, Fall 2004-Spring 2005).

Academic:

Presentations:

American Geophysical Union, 2005 Joint Assembly, May 23-27, 2005, New Orleans, "Oxygen isotope and Mg/Ca constraints on the east Pacific equatorial front from the LGM to the Holocene", talk presented by Athanasios Koutavas.

Paleoclimate Modeling Intercomparison Project II (PMIP-2) Workshop, April 3-8, 2005, Giens, France, "LGM tropical Ocean Cooling" talk presented by Athanasios Koutavas.

Paleoclimate Modeling Intercomparison Project II (PMIP-2) Workshop, April 3-8, 2005, Giens, France, "Tropical Pacific SST gradients since the LGM in relation to the ITCZ", poster presented by Athanasios Koutavas.

Paleoclimate Workshop, U.S. CLIVAR Atlantic Science Conference, Jan 2005, Rosenstiel School of Marine and Atmospheric Sciences, University of Miami, "Coupled migration of the Pacific and Atlantic ITCZ over glacial-interglacial

transitions?" talk presented by Athanasios Koutavas.

Division of Ocean and Climate Physics Seminar Series, Nov 12, 2004, Lamont-Doherty Earth Observatory of Columbia University, "Tropical Pacific SST gradients since the LGM and their relation to the ITCZ", talk presented by Athanasios Koutavas.

Workshop on ENSO and the Indian Ocean Dipole, 8th International Conference in Paleoceanography, Sep 2004, Biarritz, France, "East vs. West: Evaluating the zonal sea surface temperature gradient in the equatorial Pacific since the LGM", talk presented by Athanasios Koutavas.

NOAA-UCAR Climate and Global Change Program, 6th Summer Institute, July 2004, Steamboat Springs, Colorado, "Coupled Ocean-Atmosphere Interactions in the Eastern Tropical Pacific Since the Last Glacial Maximum", talk presented by Athanasios Koutavas.

Personnel:

Research Scientist: 1 (at no cost)
Support Staff: 1

Publications:

Journal Articles (submitted and in press):

Chiang, J. C. H., and A. Koutavas (2004), Climate Change: Tropical Flip-Flop Connections, Nature, 432, 684-685.

Stott, L., K. Cannariato, R. Thunell, G. Haug, A. Koutavas, and S. Lund (2004), Decline of surface temperature and salinity in the western tropical Pacific Ocean in the Holocene epoch, Nature, 431, 56-59.

Koutavas, A., Paleoceanography and Paleoclimatology Highlights, Geotimes, p. 42, July 2004.

Books / Articles-in-Books:

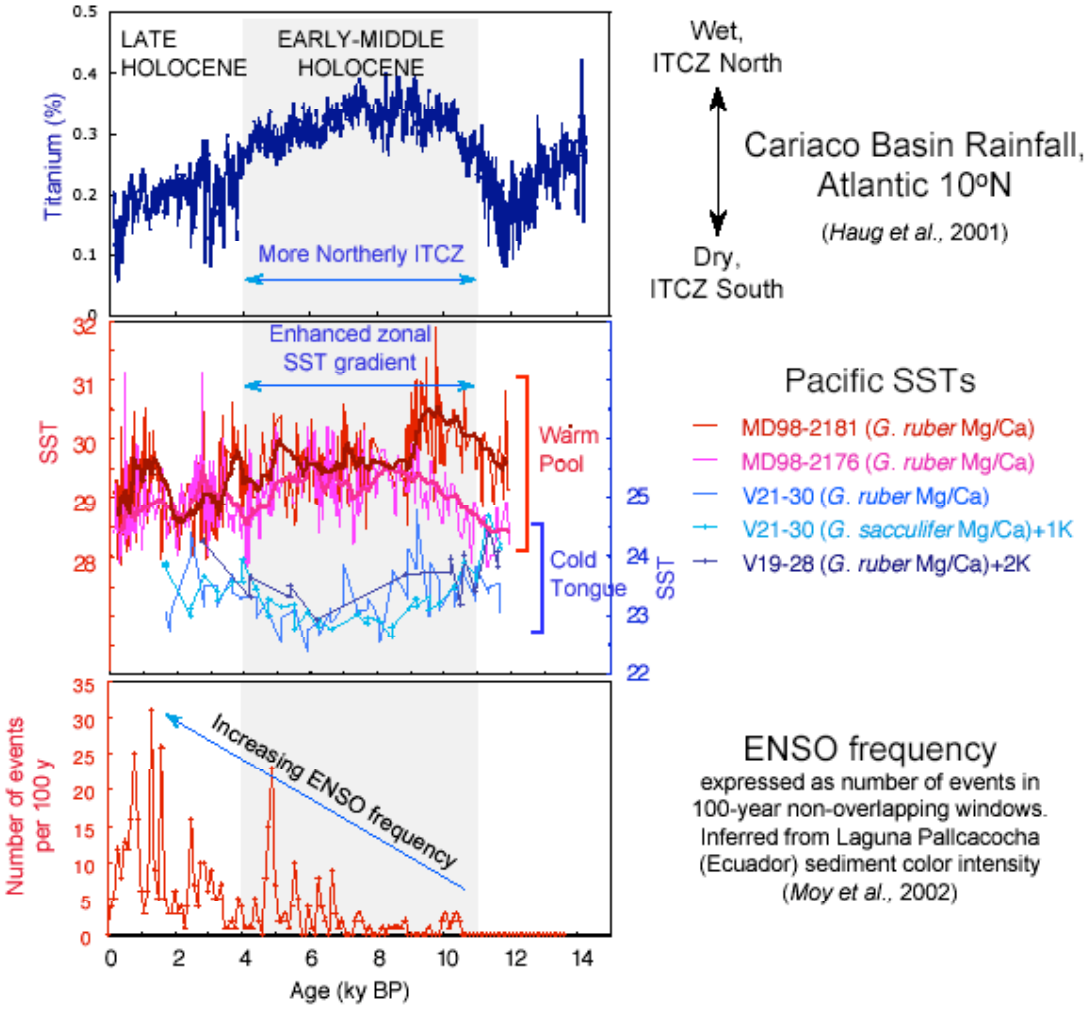
Koutavas A., and J. Lynch-Stieglitz, Variability of the marine ITCZ over the eastern Pacific during the past 30,000 years: Regional perspective and global context, In The Hadley Circulation: Present Past and Future, R. Bradley and H. Diaz, Eds., p. 347-369, Springer-Kluwer Academic Publishers, 2004.

Conference Proceedings / Workshops:

Koutavas, A., P. B. deMenocal, and J. Lynch-Stieglitz, Oxygen isotope and Mg/Ca constraints on the east Pacific equatorial front from the LGM to the Holocene, EOS Trans. AGU, (86)18, Jt. Assem. Suppl., Abstract PP21A-05. 2005.

Scanning Electron Micrograph Of A 10,000-Year-Old Fossil Foraminifer
Globigerinoides sacculifer from sediments near the Galapagos Islands in the Pacific cold tongue.

ARCHES: Patterns and Timing of Deglacial Climate Change in the Equatorial Pacific



Holocene records of ITCZ variability (top), zonal SST gradient in the Equatorial Pacific (middle), and ENSO frequency (bottom).

Project Title:	**ARCHES: Modern Observations** **Section 1: Observations** **Section 2: Moorings**
Principal Investigator:	Arnold Gordon
Affiliation:	Lamont-Doherty Earth Observatory
NOAA Program Manager:	Dr. James Todd, CLIVAR Atlantic NOAA/OGP, 301-427-2089 Ext. 2383, james.todd@noaa.gov

SECTION 1: OBSERVATIONS

Research Goals:

To understand through observations and to assess model ability to simulate, the global scale ocean circulation that is associated or possibly promotes climate change.

Education Goals:

To relate to undergraduate and graduate students at Columbia University the nature of climate change and the ocean's role in that process.

Research Progress:

During this year I concentrated on the movement of Indian Ocean thermocline water into the Atlantic Ocean around the southern rim of Africa. The transfer of this Indian Ocean water, drawn from various sources, into the upper kilometer South Atlantic displaces cooler, fresher Atlantic water that would otherwise fold into the Benguela Current, in compliance to the gyre-scale wind stress curl. In this way, what is called the Agulhas leakage makes for a warmer, saltier [though in total more buoyant] Atlantic relative to a "no Agulhas leakage" condition. This induces an Atlantic stratification more susceptible to meridional overturning circulation [MOC] associated with NADW formation. As the Agulhas leakage likely varies across a wide range of timescales, the Atlantic may at times be starved for the ingredients required for the continuation of the vigorous MOC. It is generally believed that the Agulhas leakage is primarily a consequence of a meso-scale eddy process. There have been varied studies investigating the eddies of the "Cape Basin Cauldron" from specific data sets, but what does can the nearly 100 year time series of essentially random distribution of archived hydrographic stations within the Cape Basin tell us more about the longer term eddy population and water mass properties? Eddies are identified by the depth anomalies relative to the long-term mean depth of a mid-thermocline isopycnal (a positive anomaly marks an anticyclonic eddy; negative marks a cyclonic eddy). Numerous eddies are identified in the whole region, with a 2:1 anticyclones/cyclones ratio. The eddy core water is not solely drawn from Indian Ocean: tropical and subpolar South Atlantic water also are present; the water between the eddies share equally diverse origins. Various questions arise: How do the eddy numbers and core water vary with time? Is there significant Agulhas leakage accomplished exterior to the eddies, that is within filaments or streamers of Indian Ocean water? And finally, the most important question: do ocean models properly simulate Aguilhas leakage?

In addition, I've been investigating the effects of the Indonesian throughflow on the Indian Ocean and on the Agulhas Current [and Agulhas leakage].

Highlights:

- Agulhas leakage "collects" the buoyancy introduced into the three major ocean basins from the Southern Ocean, and passes it directly into the Atlantic Ocean. This promotes the meridional overturning circulation of the Atlantic Ocean

- The Indonesian throughflow boosts the Agulhas Current by ~10Sv and in so doing enhances the sea to air heat flux south of Africa and the leakage into the Atlantic Ocean, hence the meridional overturning circulation of the Atlantic Ocean.

Societal Benefits:

I believe and recent paleo-climate studies supports the notion that the Aguilhas leakage and the associated Indonesian throughflow precondition the northern North Atlantic for formation of North Atlantic Deep Water, which strongly influences the climate of the land areas surrounding the North Atlantic. Changes in Agulhas leakage may allow prediction of changes in northern climates.

CICAR / NOAA Funded Research Connections:

Research Partnerships:

Presentation at EGU has developed into a few international research partnerships directed at palo-climate issues

Collaborators:

The ocean-modeling group at GFDL

Education and Outreach:

Research Advisor / Mentor:

Graduate:

Debra Tillinger [Department of Earth & Environmental Sciences, Columbia U]

Academic:

Presentations:

European GeoScience Union [EGU], Vienna, April 2005, invited lecture

Personnel: Totals for Sections 1 & 2

Research Scientist:	1
Research Support Staff:	3
Graduate Student:	1
Administrative:	1

Personnel funded by this project and obtaining NOAA employment within the last year: 1

Name:	Qian “Scott” Song
NOAA Agency / Lab:	GFDL
Date of Hire / Appointment:	June 2004
Title / Duties:	Post-Doc
Acceptance Date:	June 2004
Start Date:	July 1, 2004

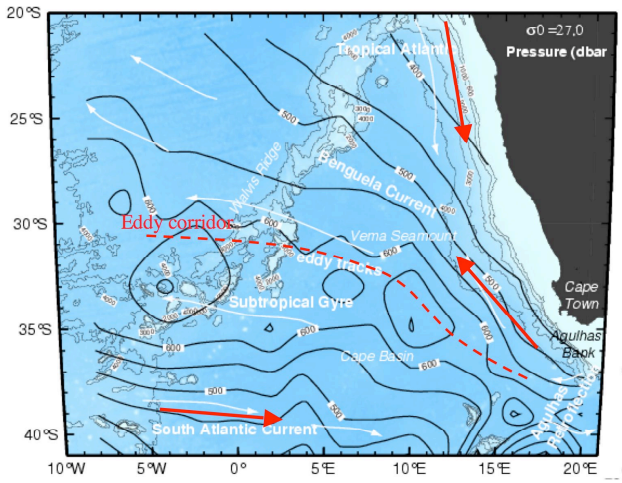
Publications:

Journal Articles (submitted and in press):

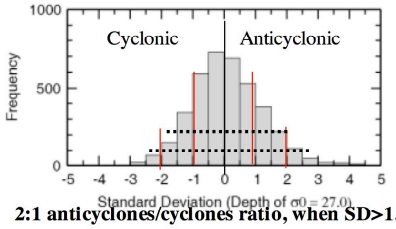
Song, Q and A. Gordon (2004) “Significance of the Vertical Profile of Indonesian Throughflow Transport on the Indian Ocean ” Geophys. Res. Lett., 31, L16307, doi:10.1029/2004GL020360.

“Koutavas, A., Paleoceanography and Paleoclimatology Highlights, Geotimes, p. 42, July 2004.

ARCHES: Modern Observations



hydrographic climatology pressure at the σ_0 27.0 isopycnal surface.

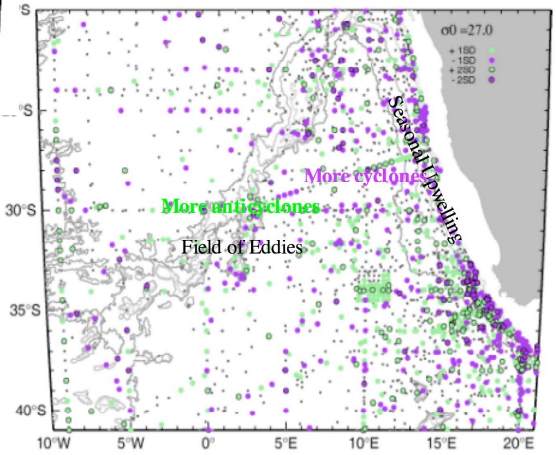


2:1 anticyclones/cyclones ratio, when SD>1.

Vertical displacement of 27.0 isopycnal surface; Large color dots 2 SD; small color dots 1 SD

Purple: Cyclonic features

Green: Anticyclonic features

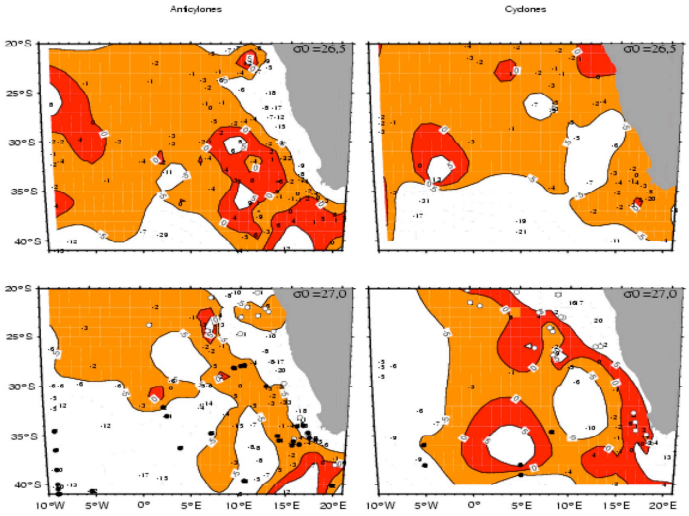


Characterizing the thermocline water within Cape Basin eddies by a Century of Hydrographic Data submitted to DSR, Claudia F. Giulivi and Arnold L. Gordon

Upper panels: salinity anomalies on the σ_0 26.5 surface; anticyclones (a) and cyclones (b); in the *lower panels*, same as in the upper panels, except for σ_0 27.0 (lower thermocline); anticyclones (c) and cyclones (d).

Shaded areas correspond to salinity differences within ±5 units from the Agulhas Current mean value at each isopycnal level.

Also plotted, those stations with low and high oxygen content at thermocline/intermediate levels.



SECTION 2: MOORINGS

Research Goals:

Install and maintain three deep and bottom water focused moorings south of the South Orkney Islands in the Northwest Weddell Sea to provide a time series of the combined outflow (currents and temperature/salinity) of Antarctic Bottom Water drawn from various sites within the Weddell Sea. As the time series is compiled, it will be examined for indications of climate variability on sub-decadal time scales. A section of CTD/tracer stations is reoccupied during the service cruises as time and conditions permit.

We rely on opportunistic scheduling of vessel time provided by a variety of sources, so timing of cruises for maintaining the moorings is approximate. Research goals remain flexible so we can take advantage of ship time opportunities as they arise.

Research Progress:

The export of Antarctic dense shelf water from the Weddell Gyre is being investigated with the Consortium on Oceans Role in Climate: AbRupt climate CHangE Studies (CORC-ARCHES) Southern Ocean Modern Observations program. Three deep and bottom water focused moorings south of the South Orkney Islands in the Northwest Weddell Sea provide a time series of the combined outflow (currents and temperature/salinity) of Antarctic Bottom Water drawn from various sites within the Weddell Sea.

First installed in April 1999, the moorings are serviced using ship time made available by other programs. The moorings were last visited in late 2001. Severe sea ice conditions prevented servicing the moorings in 2003 and 2004. In March of this year, we succeeded in reaching the mooring sites, recovering two, and redeploying a mooring at the southernmost site. The new data set extends the CORC-ARCHES Weddell Sea time series to nearly 6 years overall. Several CTD stations were occupied near the mooring sites and at several stations between the mooring locations.

The newly recovered records continuously span more than 3 years in some cases, including the time period corresponding to the breakup of the Larsen B ice shelf of the eastern Antarctic Peninsula in early 2002. It has been hypothesized that the Larsen ice shelves play a significant role in the production of deep and bottom waters in the western Weddell Sea, so the CORC-ARCHES time series may be uniquely positioned to investigate the oceanographic conditions leading up to and following the breakup of the Larsen B.

Preliminary analysis of the near-bottom potential temperature and salinity records of the CORC-ARCHES moorings from April 1999 to November 2001 suggested a seasonal cycle, albeit with some year-to-year variability. These are likely a consequence of changes in the production of dense Weddell Sea bottom water associated with varying amounts or source changes of the shelf water component. In addition, cold bottom water events lasting 1 to 2 days are embedded in the 0.1 m/s mean isobath-following eastward flow. Adding the newly recovered data to the time series clearly reveals the seasonality of the deep temperatures, with longer period signals superimposed.

We plan to revisit the mooring sites in early 2006, to service the moorings still in place, replace some aging instrumentation, and potentially add moorings to the array in collaboration with investigators from the British Antarctic Survey. Preparations are now underway for these activities

Further details and preliminary data are available at the project web site:
http://www.ldeo.columbia.edu/res/div/ocp/projects/corc.shtml

Highlights:

- Recovered and redeployed 2 moorings after a nearly 4 year deployment
- Extended the CORC-ARCHES Weddell time series data set to nearly 6 years, including a period that spans the breakup of the Larsen B ice shelf in early 2002.

Societal Benefits:

Changes in deep and bottom water outflow characteristics from the Weddell may be indicators of climate change on global scales. The CORC-ARCHES data set is potentially an important resource for identifying and understanding climate change processes.

CICAR / NOAA Funded Research Connections:

Interagency:

This research benefits from ship time provided by the NSF Office of Polar Programs at very nominal cost.

Research Partnerships:

Initiated discussions with researchers at British Antarctic Survey to collaborate in the servicing and expansion of the CORC-ARCHES mooring array.

Collaborators:

As a direct result of our ship time arrangement with OPP, we are exploring a collaboration with NSF-funded researchers to pursue studies of the Larsen ice shelf region as part of the upcoming International Polar Year.

Education and Outreach:

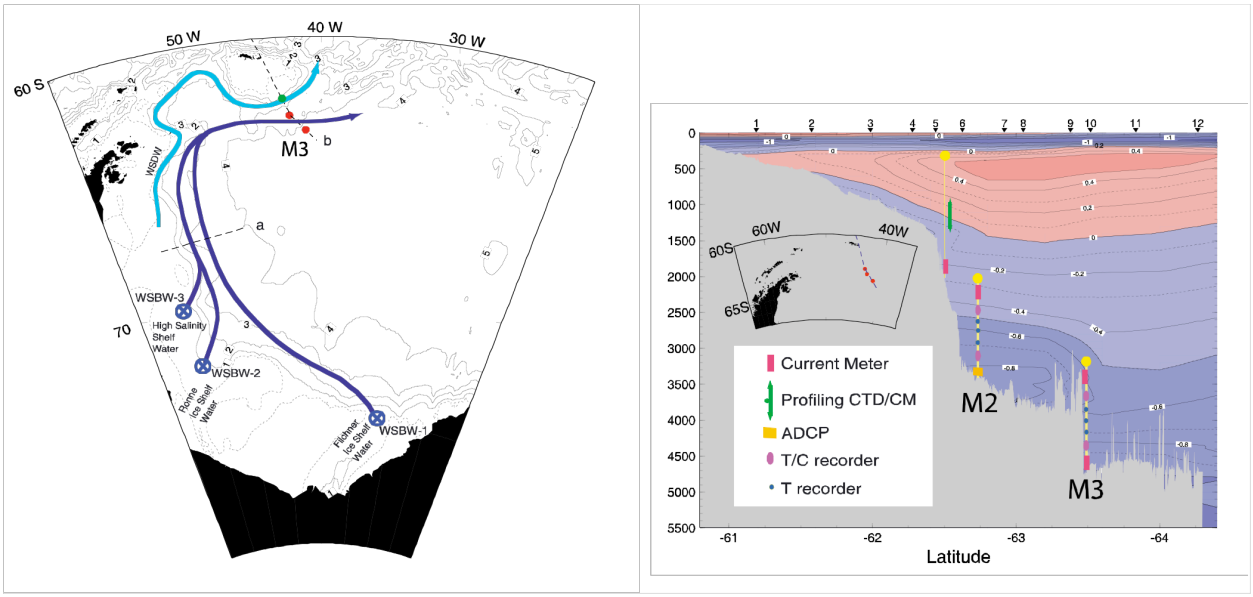
Intranet / Internet and Databases:

http://www.ldeo.columbia.edu/res/div/ocp/projects/corc.shtml

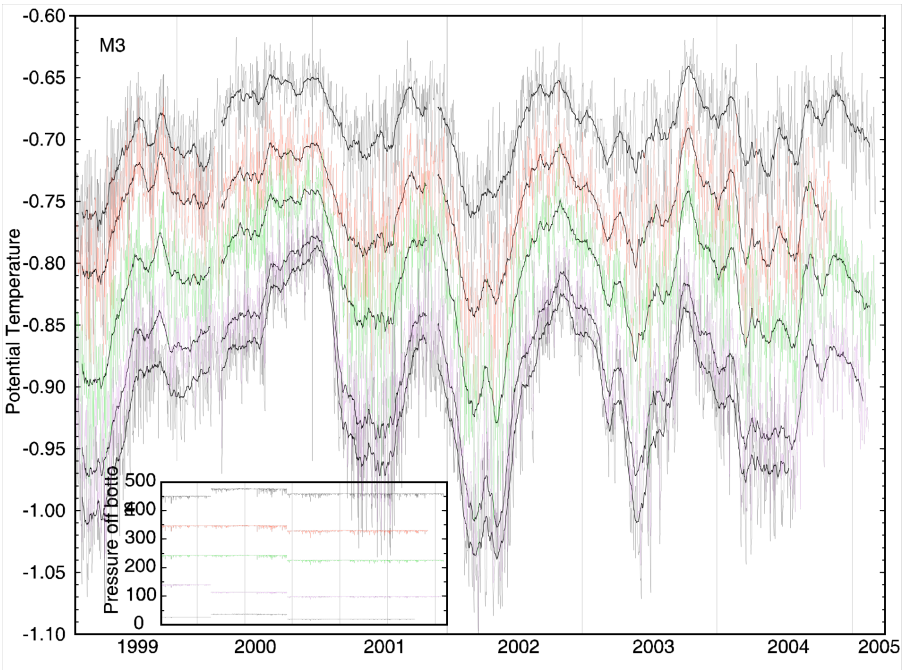
Personnel:

Research Scientist: 1
Research Support Staff: 2

ARCHES: Modern Observations SECTION 2: MOORINGS



Positions of the ARCHES moorings on a schematic representation of the major flow paths of Weddell Sea dense water bottom water, and on a potential temperature section along a track crossing the moorings.



The times series of temperature from CORC-ARCHES mooring M3 from its initial deployment in 1999 through February 2005. Note the large seasonal signal at all levels. M3 was redeployed in 2005.

Project Title: **ARCHES: Southern Ocean Modeling and Analysis**

Principal Investigator: Douglas Martinson
Affiliation: Lamont-Doherty Earth Observatory

NOAA Program Manager: Dr. James Todd, CLIVAR Atlantic NOAA/OGP, 301-427-2089 Ext. 2383, james.todd@noaa.gov

Research Goals:

Improve our quantification of the nature (magnitude, temporal-spatial distributions) of ocean-ice variability in the western Antarctic Peninsula region.

Education Goals:

Acquaint school children with Antarctic field science (accomplished by Rich Iannuzzi's "live" from the field to elementary school classrooms when in the field)

Research Progress:

1. The Year 5 Work Plan promised (as its primary goal): " to continue our investigation of better quantifying the nature of the change in ocean heat content flooding the continental shelves of the western Antarctic Peninsula" The Antarctic Peninsula is undergoing the most rapid regional warming on Earth, with extensive melting of glacial ice on its western side. We have made substantial progress on this issue, and now show (in 2 papers in preparation) that: (1) Unlike the rest of the Antarctic, this is the region where the Antarctic Circumpolar Current (ACC) flows directly along the continental slope, where its close proximity to the continental shelf allows regular flooding of the shelf with warm circumpolar deep water. This leads to an ocean winter-average sensible heat flux (the only source of heat to the region) of ~30 Wm-2. This value is obtained through techniques developed (Martinson and Iannuzzi, 1998), and corroborated by comparing these values to ones estimated by examining heat content changes from the slope (as source waters) to shelf waters. (2) The heat content over the slope (being delivered to the shelf) is considerably higher in the 1990s than in previous decades (averaging ~6 Wm-2 increase in the 1990s), but the historical data prior to the 1990s are too sparse to allow us to determine the nature of the jump. (3) The heat content on the shelf shows a steadily increasing trend, starting in 1998. (4) Turbulent diffusion coefficients are relatively small and consistent across the continental shelf (deduced from observed warming of the winter water), allowing us to estimate ACC flooding events across the shelf via a canonical shape in T-S space.
2. Stammerjohn has made progress on 1-dimensional model, but nothing is yet written. We will test the model against our observation findings (especially, for the evolution of the canonical signature of ACC waters flooding the shelf). 3-dimensional modeling goals (comparing 1 and 3 dimensional results) were not met with departure of Curchitser from program as suggested in the year 5 work plan.

Highlights:

- Quantified ocean sensible heat flux to WAP - (Earth's most rapid winter regional warming)
- Found jump in heat content in shelf waters on WAP continental shelf prior to 1990s

Societal Benefits:

Quantification of ocean's contribution to the WAP warming and possibly to rapid melt of glaciers on WAP

CICAR / NOAA Funded Research Connections:

Interagency:

National Science Foundation, particularly the Palmer Long Term Ecological Program (PAL LTER) project, focused on ecological changes, but NOAA leverage allows me to focus on physical variability in isolation.

Research Partnerships:

With PAL LTER as stated above

Collaborators:

Ducklow (VIMS), Smith, Ross, Quetin (UCSB), Vernet (Scripps), Large (NCAR)

Awards/Honors:

Yuan, "The Impact of High Latitude Climate Modes on Antarctic Sea Ice" at CliC First Science Conference, Beijing, China, 11-15, April 2005 (chosen as Honorable Mention Poster).

Education and Outreach:

Academic Outreach:

K-12:

While at sea, Rich Iannuzzi the research staffer on this project, used satellite links and daily email exchanges to communicate information about the cruise and the project to elementary schoolchildren on Long Island, New York. Rich follows up with visits to the classrooms and shares his stories, photos, and field materials with teachers and students. Rich maintains email “Q & A” with students to help further their interest in Antarctic field science.

Presentations:

Yuan (invited poster), "The Impact of High Latitude Climate Modes on Antarctic Sea Ice" at CliC First Science Conference, Beijing, China, 11-15, April 2005
Martinson (invited oral presentation), Heat flux on the western Antarctic Peninsula, Polar Institute of China, Shanghai, , 8/05
Yuan (invited oral presentation), Polar front variability in Southern Ocean Indian sector, Polar Institute of China, Shanghai, 8/05

Personnel:

Research Scientist:	2
Visiting Scientist:	1
Research Support Staff:	2
Graduate Student:	1

Publications:

Journal Articles (submitted and in press):

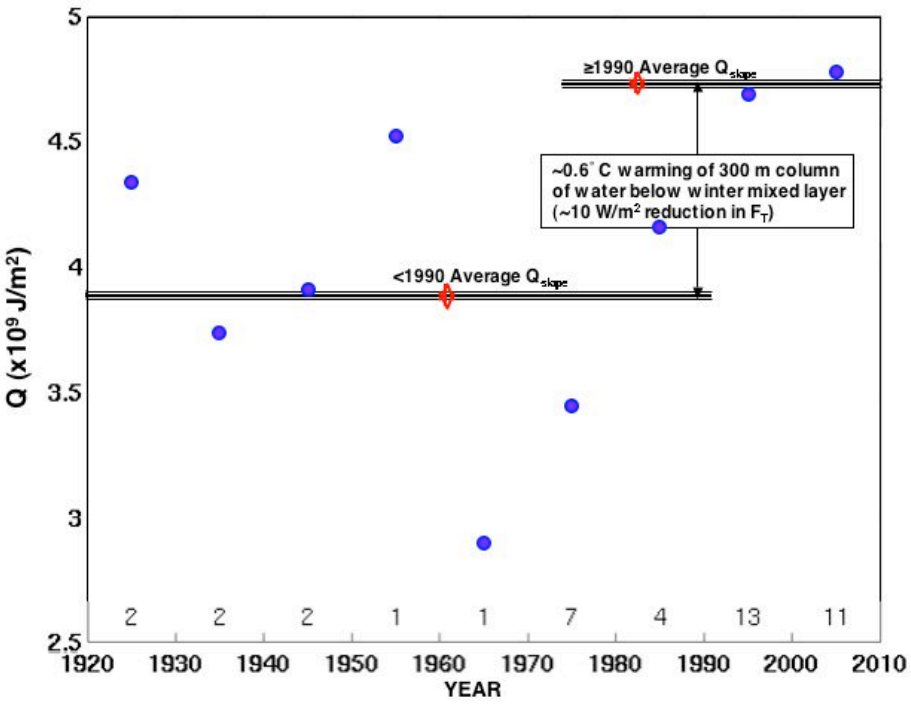
Massom, Stammerjohn, Smith, Pook, Iannuzzi, Adams, Martinson, Vernet, Quetin, Ross, Massom and Krouse , Extreme Anomalous Atmospheric Circulation in the West Antarctic Peninsula Region in the Austral Spring to Summer of 2001/2, and its Profound Impact on Sea Ice and Biota., J. Clim. (in press)

Martinson and Pitman, Role of the Arctic in Glacial terminations, in revision for Climatic Change.

Martinson, Stammerjohn, Iannuzzi, Smith, Palmer, Antarctica, long-term ecological research program first twelve years: Physical Oceanography, Spatio-Temporal Variability, submitted (to editor) of special DSR issue.

Martinson, Ventilation of ocean heat on continental shelf of western Antarctic Peninsula, submitted, Science.

ARCHES: Southern Ocean Modeling and Analysis



Jump in ocean sensible heat content (above freezing) over the continental slope of the western Antarctic Peninsula region between 1990s and previous decades (number of values used in decadal averages indicated at bottom of graph).

We have shown that this slope water is the source of heat on the continental shelf where it is vented, contributing to the Earth's most rapid regional warming. Size of multi-decadal averages given by red arrows about horizontal lines showing averages.

Project Title	**ARCHES: Tracer Observations of Deep Formation and Circulation in the Southern Ocean**
Principal Investigator:	Peter Schlosser
Affiliation:	Lamont-Doherty Earth Observatory
NOAA Program Manager:	Dr. James Todd, CLIVAR Atlantic NOAA/OGP, 301-427-2089 Ext. 2383, james.todd@noaa.gov

Research Goals:

- Improve understanding of deep-water formation in the Southern Ocean and in the North Atlantic, including its variability.

Education Goals:

- Train students in the field of observational studies of oceanic circulation, specifically in the area of tracer oceanography.

Research Progress:

The goals for this funding period included sample collection in the vicinity of the Denmark Strait and Scotland/Iceland overflows, as well as completion of measurement and beginning of evaluation of data collected during previous expeditions, including the 1994 *Aurora Australis* SR3 section, the 2001 Ross Sea cruise led by Stan Jacobs and the cruise of the *Italica* in early 2001.

Sample Collection

Sample collection was limited during year 4 in order to focus on finishing analyses and interpretation of data sets collected during previous years.

Sample Preparation and Measurements

We continued to prepare samples for measurement of helium isotope and tritium measurements from cruises to the Southern Ocean.

We are closing in on finishing the SR3 tritium data. This task has been delayed due to an unusual string of technical problems with the tritium mass spectrometer. We expect to complete these measurements during year 5 of the project. Additionally, we plan to finish all measurements from the Weddell Sea mooring site section.

Data Interpretation

We improved our interpretation of the data from the section completed along the front of the Ross Ice Shelf (AS2K). The resulting manuscript will be submitted in 2005 or early 2006.

The manuscript on the Greenland time series has been published.

Finally, we are working on the global helium isotope data sets and their relevance for ventilation in the Southern Ocean.

Highlights:

- We published a manuscript on the continued reduction of Greenland Sea Deep Water formation
- We assembled maps linking the global helium isotope distributions to the Southern Ocean where ventilation occurs
- We are close to publishing a manuscript on water/ice interaction in the Ross Sea, which shows very distinct cores of water formed by this process. This water mass participates in deep water formation in the Pacific sector of the Southern Ocean.

Societal Benefits:

The project is of public interest because it follows the evolution of the water masses in the Greenland Sea, which underwent an abrupt change around 1980 (reduction in GSDW formation rate by ca. 80%). There are also rapid changes observed in the Arctic Ocean and it will be interesting to see if these phenomena are linked to the transition into the greenhouse world.

CICAR / NOAA Funded Research Connections:

Interagency:

The research benefited my projects in the Arctic Ocean funded by NSF because the problems of deep-water formation in the Greenland Sea are linked to Arctic Ocean circulation.

Education and Outreach:

Academic Outreach:

Postsecondary:

Summer intern traineeship

Graduate:

A new Graduate Student is starting to work on the project (Brice Loose)

Academic:

Seminars:

EGU meeting Vienna 2005, AGU meeting December 2004

Personnel:

Research Scientist	1
Research Support Staff:	2
Administrative:	1
Graduate Student	1

Publications:

Journal Articles (submitted and in press):

Karstensen, J., P. Schlosser, D. Wallace, J. Bullister, and J. Blindheim, 2005. Water mass transformation in the Greenland Sea during the 1990's. *Journal of Geophysical Research*. VOL. 110, C07022, doi:10.1029/2004JC002510, 2005.

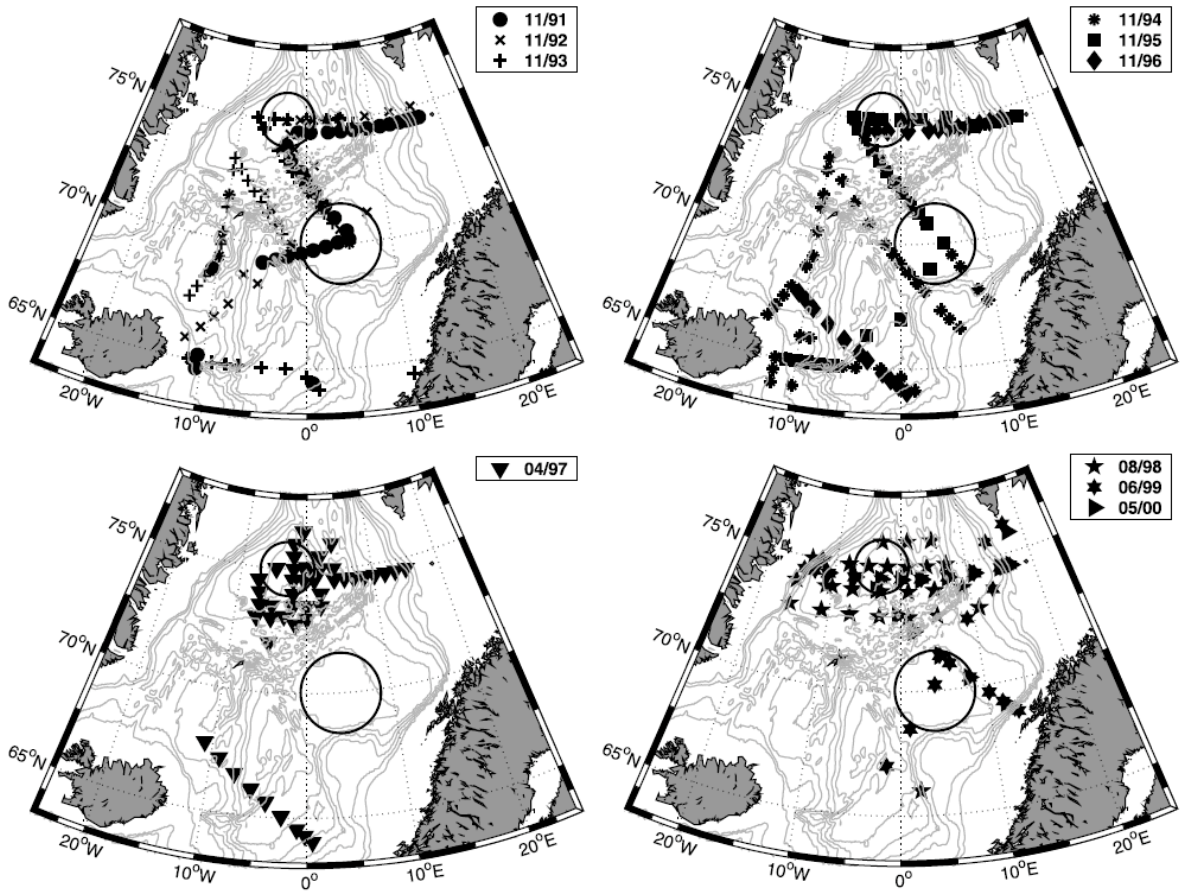


Figure 1. Station maps of RV *Johan Hjort* cruises in the Norwegian and Greenland Sea. Circled regions indicate the locations of the central gyres. Topography contours are draw in 500-m steps from 500 m to 3500 m.

Project Title: **ARCHES: Tracer Observations of Deep Formation and Circulation in the Southern Ocean**

Principal Investigator: William Smethie
Affiliation: Lamont-Doherty Earth Observatory

NOAA Program Manager: Dr. James Todd, CLIVAR Atlantic NOAA/OGP, 301-427-2089 Ext. 2383, james.todd@noaa.gov

Research Goals:

The research goals for the 2004/2005 year were to continue collecting and analyzing seawater samples from newly formed Denmark Strait Overflow Water and its precursors and from deep and bottom water outflow from the northwest Weddell Sea, and to publish a manuscript on circulation and melting under the Ross Ice Shelf based on a time series of CFC and hydrographic data. Another goal was to collect CFC data from ship of opportunity cruises to continental shelf/slope regions around the Antarctic continent.

Education Goals:

To provide research opportunities for undergraduate and graduate students in our laboratory and on cruises.

Research Progress:

The collection of samples in flame sealed glass ampoules on the Iceland Marine Research Institute seasonal cruises to the Denmark Strait region continued and samples were collected on 4 cruises. The moorings in the deep outflow from the Western Weddell Sea were reached during the austral fall for the first time in 3 years and a CTD/rosette section was taken. There was not enough manpower to obtain a full set of tracer samples, but CFC samples were collected in septum vials. This technique is easier than flame sealing, but it is not yet proven. We have measured some the samples and they appear to be ok. We also began collaboration with Dr. Keith Nicholls of the British Antarctic Survey and Povl Abrahamsen, a graduate student working for him. Povl collected CFC samples from stations along the eastern and western edges of the Fimbul Ice Shelf and from the plume of Ice Shelf Water that flowing out from beneath the Filchner Ice Shelf. Measurement of samples typically lags collection by several months or longer. This year we completed measuring the samples from the Iceland Marine Research Institute 2003 cruises. A paper entitled Circulation and melting under the Ross Ice Shelf: Estimates from evolving CFC, salinity and temperature fields in the Ross Sea was revised and published in Deep Sea Research.

Highlights:

- The rate of formation of Ice Shelf beneath the central and western Ross Ice shelf was estimated to be abut 0.85 Sv (10^{-6} m^3 sec^{-1}) and the residence time of this water beneath the Ross Ice Shelf was estimated to be 3.5 years.
- The basal melt rate of the Ross Ice Shelf that occurs during the formation of Ice Shelf Water was estimated to range from 20 to 60 km^3 yr^{-1}.

Societal Benefits:

One potential impact of global warming is melting of the Antarctic Ice shelves and a rise in sea level. This study provides an estimate of the basal melt rate of one of these ice shelves, the Ross Ice Shelf, and this is important to understanding ice shelf dynamics

CICAR / NOAA Funded Research Connections:

Collaborators:

Stan Jacobs, Lamont-Doherty Earth Observatory
Jon Olafsson, University of Iceland and the Iceland Marine Research Institute
Keith Nicholls, British Antarctic Survey

Povl Abrahamsen, British Antarctic Survey

Education and Outreach:

Research Advisor / Mentor:

Graduate:

Povl Abrahamsen is a student at the British Antarctic Survey. He collected a suite of CFC samples from the Weddell Sea which we will measure and he will work on the interpretation of the data.

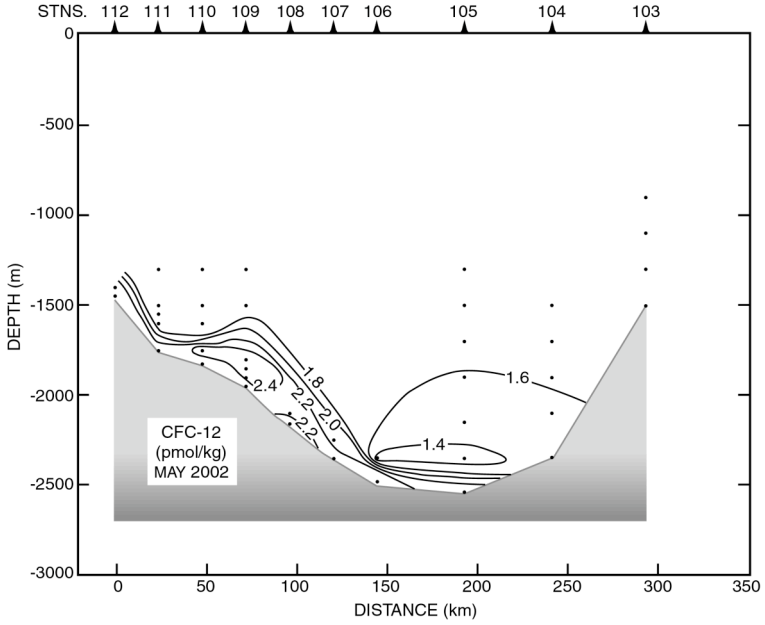
Personnel:

Research Scientist: 1 (at no cost)
Research Support Staff: 3

Publications:

Journal Articles (submitted and in press):

Smethie, W.M., Jr. and S.S. Jacobs, 2005. Circulation and Melting Under the Ross Ice Shelf: Estimates from Evolving CFC, Salinity and Temperature Fields in the Ross Sea. *Deep-Sea Research Part I,* 52(6): 959-978.

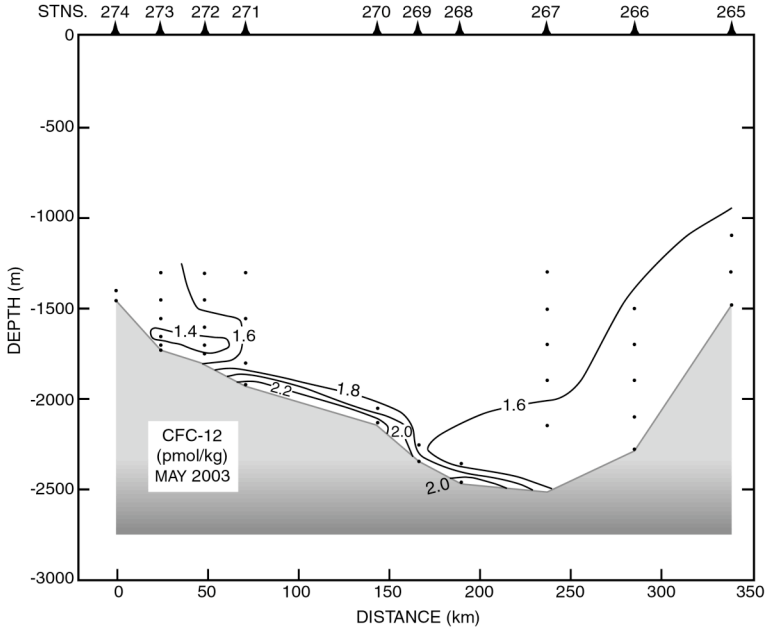


Vertical Section Of CFC-12 Extending From The East Greenland Continental Slope (Left) To The West Iceland Continental Slope (Right) 330 Km South Of The Denmark Strait Sill

These samples were collected in May 2002 as part of the seasonal surveys carried out by the Iceland Marine Science Institute. High CFC-12 concentrations above the Greenland slope extending from about 1700 m to about 2500 m are observed in the plume of Denmark Strait Overflow Water (DSOW) flowing southward and lower concentrations are observed to the east in Iceland-Scotland Overflow Water that has entered the western North Atlantic basin through the Charlie-Gibbs Fracture Zone to the south.

Vertical Section Of CFC-12 Taken In May 2003 At The Same Location Described In Figure 1.

The CFC distribution is similar to the May 2002 section with highest concentrations above the Greenland continental slope and lowest concentrations above the Iceland continental slope. But the CFC-12 concentration in the DSOW plume is lower than in May 2002 and the extent of the DSOW plume is smaller. This shows that DSOW entering the North Atlantic in May 2003 was not as well ventilated as DSOW entering in May 2003, reflecting annual variability in the formation of this important water mass.



Project Title: **Collaborative Research: Development Of A Blended Living Gridded Network Of Drought Reconstructions Of North America**

Principal Investigator: Edward Cook
Affiliation: Lamont-Doherty Earth Observatory

NOAA Program Manager: Dr. Christopher D. Miller, Climate Change Data and Detection/Climate Observations, 301-427-2376, Christopher.d.miller@noaa.gov

Research Goals:

The development of a blended living North American drought reconstruction grid, one that can be continuously updated as new instrumental data becomes available and used for operational assessments of developing droughts and wet spells.

Research Progress:

Developing the Instrumental Climate Data Fields

On September 8, 2004, co-principal investigators Edward R. Cook, Mark Eakin, Richard R. Heim, Jr., and Russell Vose met at the NCDC in Asheville to discuss the project and its instrumental climate data needs. This "meeting of the minds" was very successful and the new instrumental data grid needed by this project (see above) is in the process of being developed. Progress to this end is indicated in a March 23, 2005 email from Richard Heim, *"We have acquired the station data we need and are in the process of computing the 2.5 by 2.5 degree gridded temperature and precipitation fields. We're also running a sensitivity analysis to determine the best approach for interpolating the temperature and precipitation to take into account such things as the elevation signal. The integrated near-real time daily station data base, which we will use to generate data and products operationally for the living blended paleo drought project (and other monitoring activities), is being developed."* Thus, it is clear that we are well on our way towards establishing the necessary instrumental data grid for developing our blended living North American drought reconstruction grid.

Expanding The North American Drought Grid And Tree-Ring Network

The North American drought reconstructions recently reported on in Science do not cover important regions of northern Canada nor any part of Alaska. When the previous project started in June 2000 (NOAA Cooperative Agreement No. NA06GP0450), the decision was made to ignore those areas because there was very limited PDSI data available at the time for reconstruction in those regions and the tree-ring network itself was very sparse based on the criterion that all chronologies had to begin on or before AD 1700. This is obviously not satisfactory if a true North American drought monitoring and assessment program is to be implemented based to a significant degree on the blended living North American drought reconstructions that we will develop. Consequently, we have expanded the coverage of the 2.5 by 2.5 degree grid from the original 286 points to a target of 402 points that include more of Canada and most of Alaska. At the same time, the network of tree-ring chronologies has been increased from 835 to 1147. Many of those new ones in Alaska and Canada come from the archives of Gordon Jacoby and Rosanne D'Arrigo at the LDEO Tree-Ring Laboratory. A large number of new tree-ring chronologies from Mexico have also been added through the generosity of David Stahle and José Villanueva Díaz. In addition, the AD 1700 criterion was relaxed to include many additional tree-ring chronologies in Canada beginning on or before AD 1850. Although the new AD 1850 criterion for Canada means that the drought reconstructions there will, in many areas, be uniformly shorter than those elsewhere in North America, 150-200 years of reconstructed drought variability would still be highly useful where the instrumental data records are often less then 60 years long.

Rewriting the Drought Reconstruction Program

The computer program used for reconstructing drought over North America is being rewritten now and is mostly done. This rewrite is being done to add certain new features to it that will improve its versatility and statistical methods.

Highlights:

- The new instrumental drought grid is nearing completion.
- The North American tree-ring network has been greatly expanded.
- The computer program for reconstructing drought is nearing completion.

Societal Benefits:

Operational assessment of developing droughts compared to those that occurred in the same area over the past 1000 years will help in determining the true significance of the current drought. The long drought reconstructions may also lead to the development of improved forecasting methods.

CICAR / NOAA Funded Research Connections:

Interagency:

The drought reconstruction research was jointly supported, mainly by NOAA but also by NSF, through the NSF ESH program and the development of the North American Drought Atlas.

Education and Outreach:

Academic:

Seminars:

Cook, E.R. 2004. *Drought in America A.D. 800–2004*. **Invited talk** presented with Mark Cane at the National Academies of Science, Keck Center, Washington, D.C., October 13, 2004.

Symposiums:

Cook, E.R. 2005. *Tropical Pacific Links to Long-Term Aridity Changes in the Western United States*. **Contributed talk** presented at AGU Chapman Conference on Tropical-Extratropical Climatic Teleconnections, A Long-Term Perspective, Honolulu, Hawaii 8-11 February 2005.

Educational Tools & Databases:

The North American Drought Atlas
http://iridl.ldeo.columbia.edu/SOURCES/.LDEO/.TRL/.NADA2004/.pdsi-atlas.html

Personnel

Research Scientist: 1 (at no cost)
Research Support Staff: 1

Publications:

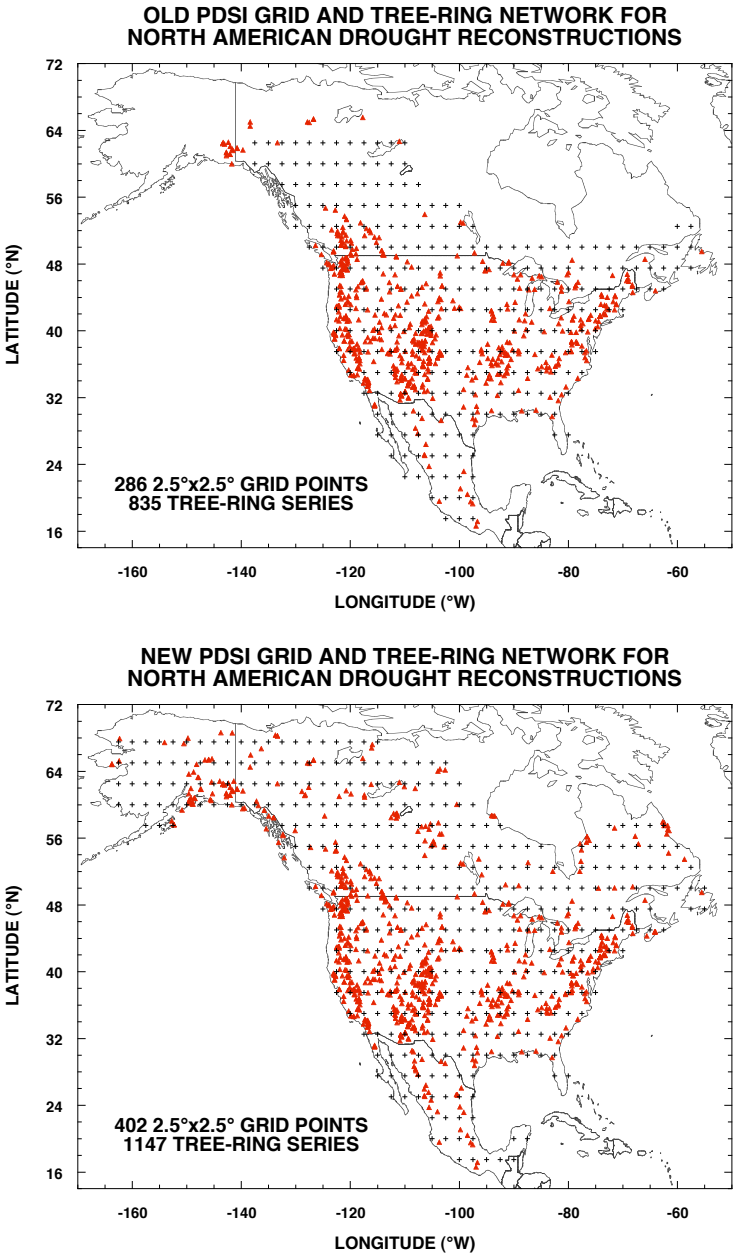
Journal Articles (submitted and in press):

Cook, E.R., Woodhouse, C., Eakin, C.M., Meko, D.M. and Stahle, D.W. 2004. Long-term aridity changes in the western United States. *Science* 306:1015-1018.

Fye, F.K., Stahle, D.W. and Cook, E.R. 2004. Twentieth century sea surface temperature patterns in the Pacific during decadal moisture regimes over the USA. *Earth Interactions* 8(22):1-22.

Woodhouse, C.W., Kunkel, K.E., Easterling. D.R. and Cook, E.R. 2005. The 20th century pluvial in the western United States. *Geophysical Research Letters* 32, L07701, doi:10.1029/2005GL022413.

Collaborative Research: Development Of A Blended Living Gridded Network Of Drought Reconstructions Of North America



The Old (Top) And New (Bottom) North American Drought Reconstruction Grids (+) And Tree-Ring Networks (D)

The grid has been expanded from 286 to 402 points and the network from 835 to 1147 annual tree-ring chronologies. The tree-ring network will also continue to grow.

Project Title: **Atmosphere and Coastal Ocean CO_2 Measurement Platform - SABSOON**

Principal Investigator: Wade McGillis
Affiliation: Lamont-Doherty Earth Observatory

NOAA Program Manager: Dr. Kathy Tedesco, Global Carbon Cycle Program, 301-427-2382, kathy.tedesco@noaa.gov

Research Goals:

- Measure the pCO_2 in the atmosphere and ocean at South Atlantic Bight Synoptic Offshore Observational Network (SABSOON). High-resolution IR detection of CO_2 will be compared to flask measurements.
- Determine ΔpCO_2 at the tower using the high-resolution IR technique in order to estimate the coastal air-sea CO_2 flux variability.
- Quantify and describe the temporal variability in atmosphere and ocean CO_2 concentrations
- Determine the relative importance of biological and physical controls on CO_2.
- Determine the influence of coastal ocean carbon on the North American terrestrial carbon cycling.

Education Goals:

The tower-based pCO_2 system is open to the community through active outreach programs though WHOI, Lamont-Doherty at Columbia University and NOAA.

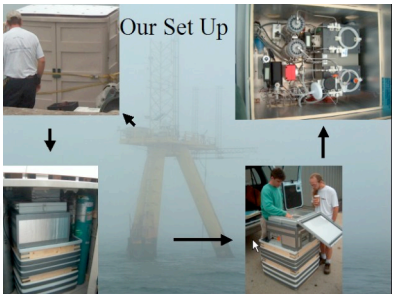
Research Progress:

The greatest assets of this project has been the development an autonomous infrared-based CO_2 sensors for the measurement of highly-accurate CO_2. A high-resolution IR-based detection pCO_2 concentrations was designed, fabricated, and deployed by the PIs on the Martha's Vineyard Coastal Tower station. This system is based around the autonomous pCO_2 system operated on the R/V Gould. The design of the infrared-based system features three significant improvements:

1) Temperature control: Thermal stabilization of the measurement system, vital to highly accurate measurements, is performed in an environmental enclosure used for in situ operation on the ocean-flux tower. A 1-m^3 reservoir of sea water is used as the thermal fly-wheel to maintain the pCO_2 measurement system to temperature fluctuation less than .5 degrees C/hr. The system uses equilibrated headspace of surface seawater that is pumped from surface waters.

2) Improved sample line delivery system: Included in the autonomous system is the use of filters and remotely adjustable flow control to ensure continuous sample delivery over month-long periods, despite heavy aerosol loads in samples.

3) Complete remote control: With a newly designed operating system, PIs can trouble-shoot, calibrate, and select sampling strategies remotely over the internet.



These three design features and the installation of this system on the tower (above) at MVO have been enacted in the first year. Years 2-3 will be dedicated to maintaining the IR system, changing the CMDL automated flask sampling kits and taking total CO_2 and O_2 measurements with monthly trips to the site. Time is allotted for dedicated analysis of the data and comparison of flask and IR based measurements of atmospheric CO_2 to confirm the accuracy of the IR-based measurements. In particular, it will be necessary to merge seawater data with monthly nutrient measurements of Dr. Richard A. Jahnke of (SkIO) and merge atmospheric data with air-parcel trajectories using high-resolution regional atmospheric transport models. We will use the HYSPLIT Lagrangian Integrated Trajectory Model from the NOAA air Resources Lab. The advantage to this model is that it can be run interactively on the Web will allow identification of potential sources of variability in atmospheric CO_2.

The advantage of atmospheric measurements on stable offshore platforms
Another key component of this study will be the inter-comparison of CMDL flask measurements, taken every 3 days, and high frequency IR measurements, taken at ½-hour intervals, of the atmospheric CO_2 mixing ratios. The main purpose of these measurements will be to establish the scales, magnitudes and sources of variability for atmospheric CO_2 mixing ratios in the marine planetary boundary layer (MPBL) off the southeastern coast of the United States. While auxiliary measurements of H_2, N_20, SF_6, CO, CH_4, and ^{13}C and from flask samples may be helpful in determining the source of variability at ~3 day intervals, IR-based measurements to interpolate between flask measurements will be crucial. The interpolation will also depend on the combination of real-time wind speed, wind direction, air temperature and barometric pressure from the MVO and R2 platform and output from Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT, http://www.arl.noaa.gov/ ss/models/hysplit.html). Integration of our atmospheric measurements with HYSPLIT will allow the identification of potential sources of variability in atmospheric CO_2. It is only through careful analysis of the combination of flask auxiliary measurements and air parcel trajectories simulations that we can identify the potential sources of variability expected in the atmospheric CO_2 mixing ratio at the SABSOON R2 platform.

Highlights:

- Successful design, deployment and testing of submicroatm pCO_2 measurements autonomously made form a coastal ocean tower.
- Discovery that coastal atmospheric CO_2 signal has terrestrial and marine sources.
- System is remotely assessed from anywhere.

Societal Benefits:

- A combination of resources including both time series stations and ship surveys of sea surface and atmospheric CO_2 on the continental margins are required to properly assess the United States coastal carbon component of the (North American Carbon Program) NACP. In this research, a system to measure CO_2 in the ocean and in the atmosphere has been invented in the laboratory, fabricated, and deployed on an ocean tower on the continental shelf of the United States. This pCO_2 system is capable of making calibrated atmospheric CO_2 measurements comparable to ***CMDL island stations*** in addition to in situ sea surface CO_2 concentrations. In addition to high-quality (0.2 ppm) and high-frequency CO_2 measurements taken every ½ hour, in the future, monthly CMDL flask analysis of CO_2, N_20, SF_6, CO, and CH_4 will allow us to quantify and understand the sources of variability in the atmosphere while continuous measurements of dissolved O_2 and monthly measurements of total CO_2 will allow us to quantify and understand sources of variability in the ocean.

- With a clear understanding of the sources and magnitude of variability that exists in the Atlantic Bight, ocean observation sites will become an integral part of the existing atmospheric CO_2 measurement network. As with other CMDL island measurement locations, the marine boundary layer offers a very stable environment for making CO_2 measurements. Unlike terrestrial sites, these sites are not as affected by large diurnal changes in the planetary

boundary layer causing a rectification of the CO_2 concentration during the summer. In the ocean we will test the hypothesis that the SAB is net heterotrophic. The coastal tower system will also address the following questions: [1] How accurate can CO_2 measurements be made on unmanned platforms off the coast (less than 0.2 ppm)? [2] What are the scales of variability in atmospheric and surface water CO_2 concentrations and air-sea fluxes in the coastal ocean?

CICAR / NOAA Funded Research Connections:

Interagency:

NOAA OGP with interagency collaborations between NSF and NASA

Research Partnerships:

Partnerships with the Woods Hole Oceanographic Institution Martha's Vineyard Observatory and the Skidaway Institution of Oceanography the South Atlantic Bight Synoptic Ocean Observational Network (SABSOON).

Collaborators:

Pieter Tans, Tom Conway, and Colm Sweeny from the NOAA/CMDL laboratory in Boulder Collorado

Public Relations:

Community Outreach

The work is publicized on the Coastal Observatory Martha's Vineyard

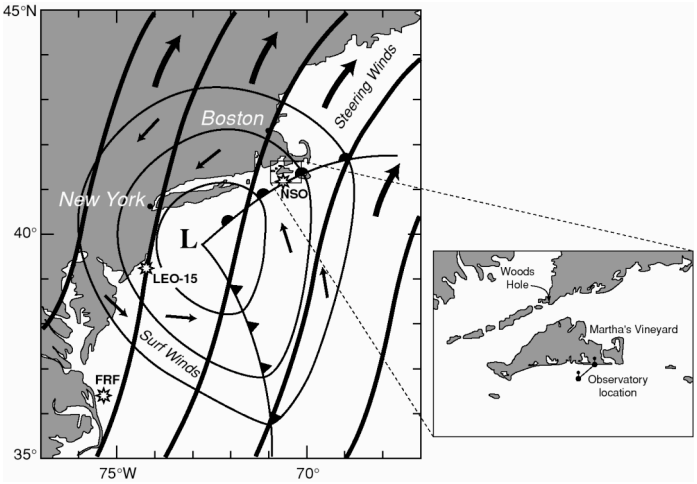
Intranet / Internet:

www.whoi.edu/mvco
http://www.ldeo.columbia.edu/~csweeney/tower/tower_co2_sys_wk1.htm

Personnel:

Research Scientist:	2 (1 at no cost)
Research Support Staff:	3 (2 at no cost)
Administrative:	2 (at no cost)
Graduate Student	1
Undergraduate Student	1

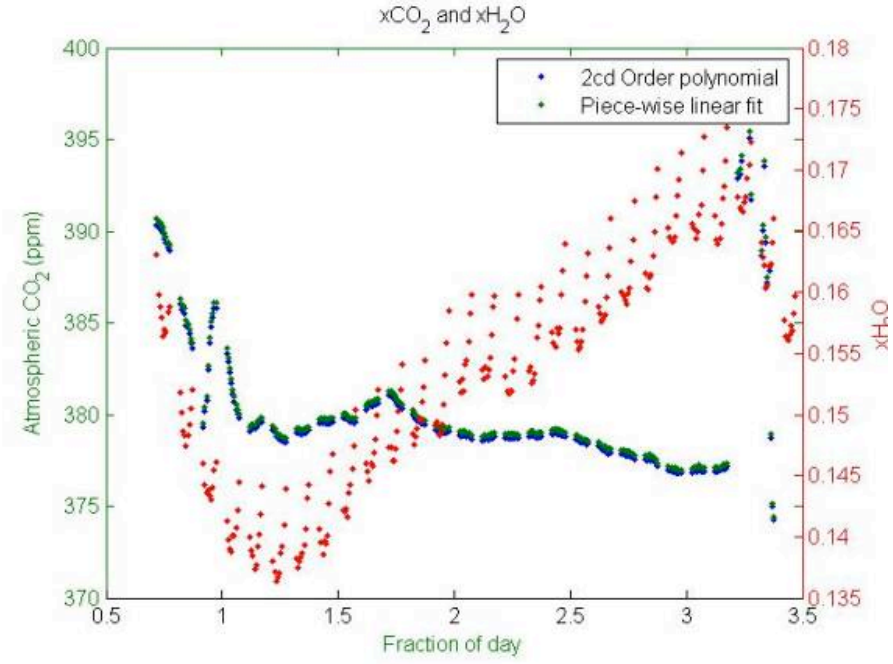
Atmosphere and Coastal Ocean CO_2 Measurement Platform - SABSOON



Synoptic Weather Mixes Air From Contiguous US With Air Over Coastal Oceans
East Coast Observational system (ECOsystem) is a network of coastal sites that currently provides information on physical processes in the ocean and atmosphere. CO_2 measurements at the South Atlantic Bight Synoptic Ocean Observational Network (SABSOON) would complement the Martha's Vineyard Observatory (MVO). All together, ECOsystem will provide a range of coastal carbon processes that influence the carbon budget on North America

This figure shows atmospheric CO_2 (left axis) and water vapor (right axis) over a 3-day period (August 13 – August 15, 2005).

The dry concentration of CO_2 remains steady at global mean values (380 ppm) for most of this period but shows plumes of atmospheric CO_2, which are presumably from point sources inland. Here we need to look at wind direction and trajectory maps during this time period.



Project Title: **SOLAS OASIS Platform**

Principal Investigator: Wade McGillis
Affiliation: Lamont-Doherty Earth Observatory

NOAA Program Manager: Jorgeann Hiebert, NOAA Environmental Technology Lab, 303-497-6856, jorgeann.Hiebert@noaa.gov

Research Goals:

This project focuses on development of an Ocean-Atmosphere Sensor Integration System (OASIS) that will be capable of taking a wide variety of measurements on oceanic and atmospheric processes. OASIS is composed of three parts: (a) reusable, solar-powered, autonomous, navigable, 2-way communication-capable (via Iridium modems), GPS-located, low cost (<$20K) Surface Autonomous Vehicles (SAVs); (b) low-cost, low-power, biogeochemical and air-sea process sensors; and, (c) NASA's "Sensor Web Technology" software for command and control of individual and group OASIS fleet deployments. The project will interface a suite of air-sea flux and biogeochemical sensors on the OASIS fleet; implement NASA's Sensor Web Technology (SWT) software to support command and control of the craft; and, develop and field-test both fleet and individual crafts under a variety of scenarios aimed at addressing several focused science and environmental monitoring issues. A variety of operational sampling modes—Station Keeping, Ocean Transit, Coastal Mapping, and Dynamic Cluster Mapping—will be developed. In addition to already commercially available sensors, such as Conductivity-Temperature devices for sea surface temperature (SST) and salinity (SSS), additional sensors will be developed and interfaced to measure air-sea gas, momentum and heat fluxes and ocean bio-optical properties. Field-testing of the crafts and sensor suites will focus on addressing the interplay between air-sea flux processes, ocean physics and ocean phytoplankton dynamics.

Education Goals:

The educational and outreach goals are described in the main proposal by the PI John Moison at the NASA Wallops Flight Facility:
http://www.csc.noaa.gov/cots/progress_reports/oasis_04.pdf.

This project will be involved in several educational efforts. A brief description of each is presented below:

Undergraduate Summer Internships: Each summer, NASA sponsors a number of undergraduate students to participate in a number of summer internship programs. The engineering group at NASA will seek to involve several of these interns in the development and testing portion of this project.

NASA-UMES Summer Internship Program (NUSIP): NASA is presently sponsoring a summer internship program with the University of Maryland, Eastern Shore (an historically black college) to bring young engineering, math and computer science students to work at NASA Goddard Space Flight Center at Wallops Island. John Moisan will work with the programs coordinator (Ms. Lisa Johnson) to obtain one to two students per year to work with NASA engineers in developing OASIS platforms, sensors and software.

Summer High School Internships: NASA Goddard Space Flight Center has summer high school internships available for local area high school students to introduce them to engineering, math, and science careers. The proposed effort will support the participation of two additional summer high school students in this program. In the past years, students have worked on both laboratory and web-development projects. The focus of the proposed internships will be to give the students experience in applied engineering, sensor and software

projects. Students will participate over a ten-week period. They will be given a focused project that they will work with engineers or programmers to complete.

NOAA-ETL Summer High School Program: During the past 3 years, NOAA-ETL has established a relationship with a group of exceptional high school science students from the State College Area High School in Central Pennsylvania. Under the guidance of Earth Science Teacher Dr. Thomas Arnold, these students travel to a remote location to conduct a small-scale data-taking expedition. Additional high school students from Scotland also participate in these experiments, which are designed to give the students real-life experience in the field. The students learn to conduct science and to use the meteorological, biological, and hydrological instrumentation in an actual field expedition. As a result of their efforts, the students are able to compile 2-3 posters to be presented at the annual American Meteorological Society's Conference on Education.

Co-Investigator Jeffrey Hare (University of Colorado and NOAA-ETL) has acted as advisor to these expeditions during the Wyoming-2000 and Montana-2002 experiments. The responsibilities include providing instruments, masts, and data-logging computers, traveling to the camp to instruct the students on the use of the equipment, and providing guidance to the students during the analysis, interpretation, and presentation stages.

As an element of the proposed research, the high school students from State College Area High School will be invited to visit the NASA Wallops facility in order to witness the development of the OASIS platform and experience the exciting possibilities that the vehicle offers. This will give the advanced high school science students the opportunity to see the NASA scientists and engineers at work and give them exposure to the possibilities that working in the sciences provides. Additional field trips may be scheduled for the nearby Wallops Island Marine Science Center, which is operated by the Marine Sciences Consortium of Pennsylvania. Funds are requested within this proposal to support this planned activity.

Research Progress:

The main science objectives of this proposal are to develop the OASIS system to measure the variability of physical, chemical and biological variables to improve the predictive power of important biogeochemical processes. OASIS has the ability to optimally achieve the following tasks over a relatively wide geographic range:

1) **Air-sea CO_2 fluxes and pCO_2 variability:** Measuring the air-sea CO_2 flux continuously from autonomous surface platform using micrometeorological approaches in order to determine the dependence of gas exchange on atmospheric forcing, surface ocean physical, biological, and chemical processes. Measuring the temporal variability and horizontal structure of CO_2 concentrations to determine the flux footprint of the platform.
2) **DMS: sea-air fluxes and biological processes:** The dynamics of DMS in surface waters has important consequences for the sulfur content of local air masses. Due to its ubiquitous supersaturation relative to the atmosphere, DMS is a particularly good candidate for characterizing gas exchanges rates at the surface ocean. Given its complex biogeochemistry in ocean water linked to phytoplankton speciation and grazing and microbial processes, DMS is also a likely indicator of variability in biological processes on short distance scales.
3) **Detection and Physiological State of Harmful Algal Bloom:** Identifying the taxonomic composition is essential for predicting the harmful algal blooms. Remote sensing of pigments and variable fluorescence on the OASIS platform can be used to indicate both the composition and the physiological status of bloom species. *In situ* measurement of phytoplankton-inherent optical properties along various length scales will help improve algorithms for interpreting airborne and satellite sensors and will potentially target initial bloom-seeding sources.
4) **Atmospheric forcing and variability**: Measuring air-sea turbulent fluxes. The OASIS platform provides an ideal platform for deployment of advanced meteorological sensors.

The absence of obstructions to wind will allow measurements of heat, momentum, and gas flux in an unperturbed marine boundary layer.

Air-sea CO_2 fluxes and pCO_2 variability: Physical controls on CO_2 include air-sea gas transfer and circulation. The transfer of CO_2 between the atmosphere and ocean, F_{CO2}, is commonly parameterized as

$$F_{CO_2} = s_{CO_2} k_{CO2} \Delta pCO_2 \quad , \qquad (1)$$

where F is the air-sea CO_2 flux, k_{CO2} is the gas transfer velocity, s_{CO2} is the solubility of CO_2 (a function of temperature and salinity), and ΔpCO_2 is the difference in partial pressure of CO_2 between the water (pCO_{2w}) and the atmosphere (pCO_{2a}). The gas transfer velocity is known to vary with wind speed, atmospheric stability, sea-state, Schmidt number (a gas-dependent function of temperature), and a host of surface processes (Jähne and Monahan, 1995; Donelan *et al.,* 2001). Additionally, at low wind speeds, gas transfer is enhanced for carbon dioxide due to chemical reactions within the aqueous boundary layer (Wanninkhof, 1992).

Surface water pCO_2 surveys do not yield air-sea CO_2 fluxes by themselves. To calculate flux the gas transfer velocity, k, must be known. To obtain regional fluxes we must be able to relate the gas transfer velocity to environmental forcing and obtain global estimates of k on daily timescales.

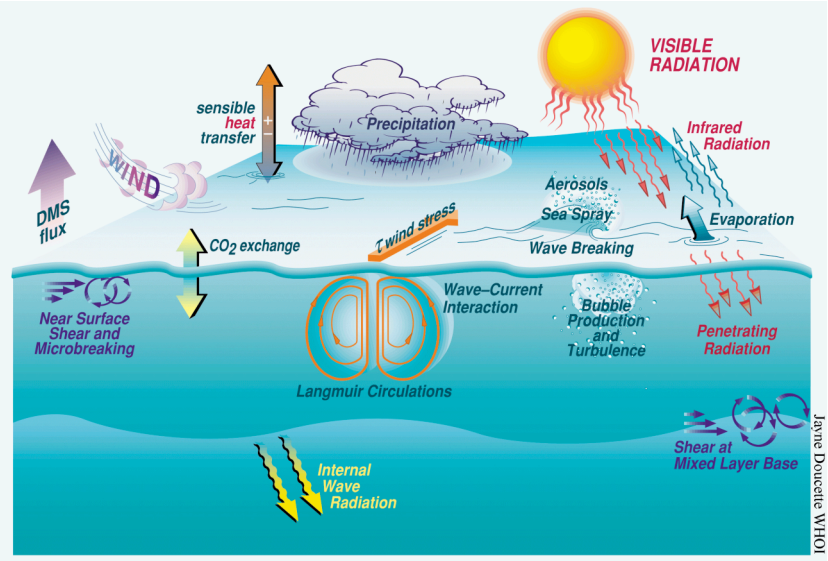
The myriad of physical processes that affect gas transfer are reflected in a wide variety of transfer velocity parameterizations and there is little consensus in the scientific community of the relative importance of each of these processes. As a result, global carbon budgets employ various transfer velocity parameterizations, which ultimately produces a wide variety of ocean source/sink estimates. The use of an accurate parameterization for the CO_2 transfer velocity in global carbon budgets would remove one major source of ambiguity. Direct measurements of the CO_2 flux over a wide range of atmospheric and oceanographic conditions would improve the parameterizations of the transfer velocity. In particular, the direct covariance technique has the potential to circumvent many of the problems associated with the indirect measurements of gas exchange because it is a measurement of the gas flux at the scale of the processes controlling the flux. For these reasons, long-term, continuous, air-water CO_2 fluxes are necessary.

Until recently, only a few attempts of direct measurements of air-sea gas fluxes have been performed. Methods to measure air-sea gas flux, particularly CO_2, led to much controversy in defining the magnitude of the oceanic flux [*Broecker et al.,* 1986]. Because of the lack of direct flux measurements, parameterizations for air-sea gas exchange were based on indirect measurements. Models combine sea-surface measurements of concentration with parameterizations for the gas exchange rate. The number of parameterizations developed over the years to describe gas transfer across the sea surface is extensive. However, to date, all such relationships have sprung from observations made over large spatial or time scales, which smooth out even the synoptic-scale variability of atmospheric forcing. Algorithms relating gas exchange to wind speed are either developed from compilations of field data [*Nightingale et al.*, 2000], from controlled studies at a single field or laboratory site [*Watson et al.*, 1991], or a combination of field and laboratory data [*Liss and Merlivat*, 1986]. Several recent gas exchange models are constructed to reconcile the budgets of radiocarbon and radon tracers [*Wanninkhof*, 1992; *Wanninkhof and McGillis*, 1999]. However, lack of sufficiently decisive data has prevented confirmation of a single relationship for air-sea gas exchange.

Several advances in gas flux measurements address the concerns related to the application in oceanic conditions [*Fairall et al.,* 2000]. Advances in air-side gradient and covariance measurements have decreased the temporal and spatial scale; in particular, the ocean-atmosphere direct covariance method for CO_2 [*McGillis et al.,* 2001a; *McGillis et al.,* 2001b] and the gradient method for DMS [*Dacey et al.,* 1999; *McGillis et al.,* 2001b]. For air-sea fluxes of more soluble gases that can be used as proxies for air-sea fluxes of CO_2 (ie., DMS) the

atmospheric boundary layer is also considered [*McGillis et al.,* 2000]. Advances in air-sea gas flux measurements have relied on: (1.) the ability to adequately remove the motion contamination, (2.) the deployment of the sensor package at a location that minimizes the effect of flow distortion around an ocean-going vessel, (3.) have adequate signal levels and frequency response to compute the gas flux using currently available sensors, (4.) measure fluxes coincident with surface water gas concentrations, and (5.) perform extended time series of flux measurements.

The goal of this proposal is to provide accurate air-sea CO_2 fluxes in near real-time. Constraining global and regional fluxes on short timescales and providing an understanding of the controls on these fluxes, essential to understanding the processes controlling the fluxes. These fluxes would be a result of models and real time observations of parameters from which the air-sea CO_2 fluxes can be calculated.



Task Milestone Date for 2005
LDEO/ETL team meets with OASIS PI's to integrate design September 2005
LDEO builds enclosure hubs instrument systems September 2005
OASIS HAB Inst. Field tests August 2005
LDEO mounts system on OASIS September 2005
LDEO/ETL team test air-sea flux system October 2005
LDEO/ETL/OASIS team field test flux system at Duck NC October 2005
Coastal Observation II – A Continuation of the OASIS Project

Highlights:

- High-end meteorological sensors for air-sea heat fluxes, gas fluxes, and momentum fluxes have been procured.
- Columbia University and NOAA/ETL are fabricating sensor suite.
- Fall 2005 the Platform will be tested at the Duck Field Research Facility (http://frf.usace.army.mil/).

Societal Benefits:

The primary mode of our community outreach efforts will occur through presenting our results in a timely manner through publication in scientific journals and through presentations at meetings and workshops. In addition, we will broadcast the developments of the platform and the sensor suites through regular notices on the **Ocean.US** web site newsletter. Additional outreach efforts will be conducted through the NASA outreach coordinator, Brian Campbell. Mr.

Campbell's task is to present NASA science advances to the education community through lectures and web notifications.

CICAR / NOAA Funded Research Connections:

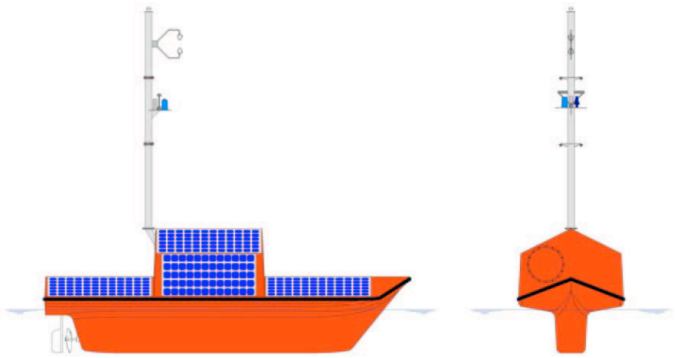
Collaborators:

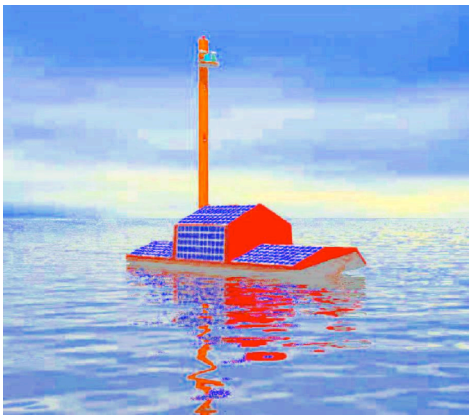
John Moison (NASA/WFF), Chris Fairall (NOAA/ETL)

Personnel:

Research Scientist: 1 (at no cost)
Research Support Staff: 1
Undergraduate Student: 2

SOLAS OASIS Platform





Drawings of OASIS
The propulsion system, solar panel power arrangement, and mast are show. Sensors will be mounted on the mast and hull. The sensor enclosure hub will be a cylindrical enclosure ensconced in the OASIS hull.

The meteorological package will be integrated with OASIS Sept-Nov 2005. The instruments include motion system, 3-D sonic anemometry, water vapor, temperature, and carbon dioxide.

Theme III: Applications Research

Two (2) research projects have as their secondary definition Theme III:

1. *Multivariate Approach to Ensemble Reconstruction of Historical Marine Surface Winds from Ships and Satellites* (major Theme I) – PI Alexey Kaplan

2. *Collaborative Research: Development of a Blended Living Gridded Network of Drought Reconstructions of North America* (major Theme II) – PI Edward Cook

Task IV: Collaborative Education Program and Projects

TASK IV PROJECTS:

THEME I: Earth System Modeling

Project Title:	**Understanding Climate Change from the Medieval Warm Period to the Greenhouse Future**
Principal Investigator:	Richard Seager
Affiliation:	Lamont-Doherty Earth Observatory
NOAA Program Manager:	Ants Leetmaa, GFDL / LDEO Collaborative, 609-452-6502, ants.leetma@noaa.gov

Research Goals:

Model and understand the changes in global climate, and changes in climate variability, over the period from 1000AD to 2200AD. Our primary purpose is to understand future changes in climate as a result of changes in external forcing and greenhouse gas concentration with particular emphasis on regional changes such as variations in rainfall over North America, Africa, and the Asian Monsoon. The idea is to put present and projected climate variability in the context of the past. Climate variability in the modern period of instrumental data is analyzed and simulated to determine the mechanisms of climate variability and climate change. The same models will be used to simulate the climate history of the last millennium and the results compare to proxy evidence to see if the knowledge gained on the modern period can also explain these past climate variations. This will enable us to assign more confidence to model predictions of future climate. The last millennium is chosen a time when significant undulations in climate: the so-called Medieval Warm Period and the Little Ice Age occurs and there is information on variations in solar and volcanic forcing and sufficient high-resolution proxy records available for model verification. The project emphasizes collaboration with GFDL scientists to address research goals that are common to LDEO AND GFDL and support for young researchers.

Education Goals:

Facilitate maximum involvement of young scientists by dedicating most of the funding to support advanced PhD students and postdoctoral scientist. Create an environment, which fosters cross-disciplinary collaboration between meteorologists, oceanographers, applied mathematicians, and geochemists.

Research Progress:

In the first year of the project attention has mostly been on climate variations in the instrumental record. Additional work on climate change over the last 1000 years has been done, although not in collaboration, yet, with GFDL. Further work has been conducted on climate system processes that we anticipate to be relevant to climate change over the last 1000 years and in the future, most of it in collaboration with GFDL. The work has focused on many topics, including mid-latitude droughts, annular mode variations, tropical climate change, variations of the THC, water

vapor transports in a changing climate and diagnostic comparisons of variability in Nature and the GFDL climate models. Major achievements were made in the following: (i) The global pattern of persistent hydroclimatic anomalies in the last 150 years (C. Herweijer mentored by R. Seager); (ii) The 1976/77 shift in precipitation across the Americas – causality and relation to N. American drought including a comparison to the late 20 century drought (H.-P. Huang with R. Seager, Y. Kushnir in collaboration with N.-C. Lau at GFDL); (iii) Mechanisms of hemispherically and zonally symmetric circulation anomalies in response to tropical forcing (H.P. Huang. R. Seager, M. Ting and N.C. Lau); (iv) ENSO variability in the last millennium in an intermediate coupled model with realistic solar and volcanic forcing (J. Emile-Geay mentored by M. Cane, R. Seager); (v) ENSO trends in the GFDL model simulations (N. Walker mentored by M. Cane, R. Seager); (vi) The Asian Monsoon and ENSO – understanding the tenuous association in the last century and a half (C. Ihara mentored by M. Cane and Y. Kushnir, collaboration with N.-C. Lau at GFDL). (vii) Polar climate simulation in the GFDL model (R. Cullather); (viii) Stratospheric variability and tropospheric linkages in the GFDL model (A. Charlton with L. Polvani have working with V. Ramaswamy, J. Austin and J. Wilson at GFDL); (ix) Mechanisms controlling subtropical water vapor (J. Galewsky with A. Sobel – Columbia APAM and I. Held – GFDL); (x) Tropical Atlantic climate biases in the GFDL model (M. Biasutti, with A. Sobel and Y. Kushnir); (xi) Increasing computational efficiency of climate models (S. Khatiwala at LDEO and S. Griffies, A. Gnanadesikan, and A. Adcroft at GFDL); (xii) African droughts future scenarios in comparison to past changes (M. Biasutti and A. Sobel in collaboration with A. Giannini – IRI and I. Held – GFDL).

Highlights:

- North American droughts are forced by decadal SST anomalies in the tropical Pacific
- Topography is important for the simulation of the low-level jet and summertime rainfall over the North American Great Plains
- Indian Ocean SST can alleviate Indian Monsoon droughts during El Niño events
- Objective algorithm used to search the history of stratospheric “sudden warmings” in GFDL model simulations.
- Improved “matrix transport” method for fast simulation of biogeochemical tracer transport in ocean models
- Tracing subtropical water vapor in a GFDL model shown that the generation of dry subtropical air is due mainly to isentropic transport by extratropical eddies and to a lesser extent to the Hadley circulation
- Develop web-browser based LDEO server for GFDL model data. This allows LDEO researches rapid access to GFDL model data for analysis

Societal Benefits:

Increase understanding of climate processes leading to droughts in the US and other locations

- Increased understanding of tropical forcing of global climate variations
- Increased understanding of climate sensitivity to solar and volcanic forcing
- Putting human influence on climate in the context of natural climate variability
- Seeking to improve Indian Summer Monsoon rainfall prediction
- Advancing climate modeling through model-observation comparisons
- Introducing young scientists to NOAA related science and research priorities

CICAR / NOAA Funded Research Connections:

Some research topics under this project are related to work supported by NSF and NASA.

Research Partnerships:

With NOAA GFDL. Between C.U. APAM and LDEO OCP.

Collaborators:

The project involves close collaboration between GFDL and Columbia University researchers. It also involves collaboration with W. Robinson, U. of Illinois and V. de la Peña C.U. Dept of Statistics.

Education and Outreach:

Academic Outreach:

K-12:

Through LDEO annual Open House and Columbia University Community Outreach activities

Postsecondary:

Through LDEO annual Open House and Columbia University Community Outreach activities

Research Advisor / Mentor:

Undergraduate:

Eric Jacobsen (Senior, University of Chicago), mentored by R. Seager and Y. Kushnir

Graduate:

Celine Herweijer (PhD student), Mentored by R. Seager; Chie Ihara (PhD student) mentored by M. Cane and Y. Kushnir); Natasha Walker (PhD student) mentored by M. Cane, R. Seager; Julien Emile Geay (PhD student) mentored by M. Cane, R. Seager.

Academic:

Presentations:

Huei-Ping Huang and Celine Herweijer presented results of their work under this project at the workshop on “Predicting Drought on Seasonal to Decadal Time Scales” held at the University of Maryland, during May 17-19, 2005.

Chie Ihara presented results of her study at the 2004 AGU Fall meeting in San Francisco, CA. Michela Biasutti presented results of her tropical Atlantic GCM biases study at the CLIVAR Atlantic PI meeting in Miami, FL during January 21 – February 2, 2005.

“A New Climatology of Stratospheric Sudden Warmings"
Lorenzo M Polvani and Andrew Charlton given at the "2005 SPARC/GRIPS Workshop"
Toronto, Ontario - March 14-17, 2005

"A New Look at Stratospheric Warming Events in Reanalysis Datasets and Numerical Models"
Andrew Charlton and Lorenzo M Polvani given at the "13th Conference on Middle Atmosphere" Cambridge, Mass - June 13-17, 2005

Symposiums:

Richard Seager was on the organizing committee of the workshop on “Predicting Drought on Seasonal to Decadal Time Scales” held at the University of Maryland, during May 17-19, 2005.

Two project PI meetings were conducted during this budget year. One was held at GFDL on February 24, 2005 and the second held at LDEO on June 23, 2005. The first meeting was informal and was mostly dedicated to unstructured exchange of ideas and planning future activities. The second meeting was used for reporting progress and planning future activities under this collaborative project. The meeting agenda is attached below:

Intranet / Internet:

Drought pages on LDEO/OCP website at:
http://www.ldeo.columbia.edu/res/div/ocp/drought/;

Educational Tools:

Databases:

Created local, web-based access to all of LDEO GCM ensembles as well as GFDL model output

Personnel:

Research Scientist / Faculty:	13, most at no cost
Research Support Staff:	3
Post Doctoral Fellow:	4
Graduate Student:	2
Undergraduate Student:	1 summer intern

Publications:

Journal Articles (submitted and in press):

Biasutti, M., A. H. Sobel and Y. Kushnir, 2005: GCM precipitation biases in the tropical Atlantic. J. Climate, submitted.

Cullather, R. et al., 2005: An assessment of IPCC coupled model simulations of the Antarctic climate, Clim. Dynamics, submitted.

Galewsky, J., A. H. Sobel and I. M. Held, 2005: Diagnosis of subtropical humidity dynamics using tracers of last saturation, J. Atmos. Sci., in press.

Giulivi, C. and A. L. Gordon 2005: Characterizing the thermocline water within Cape Basin eddies by a century of hydrographic data. Deep Sea Res., submitted.

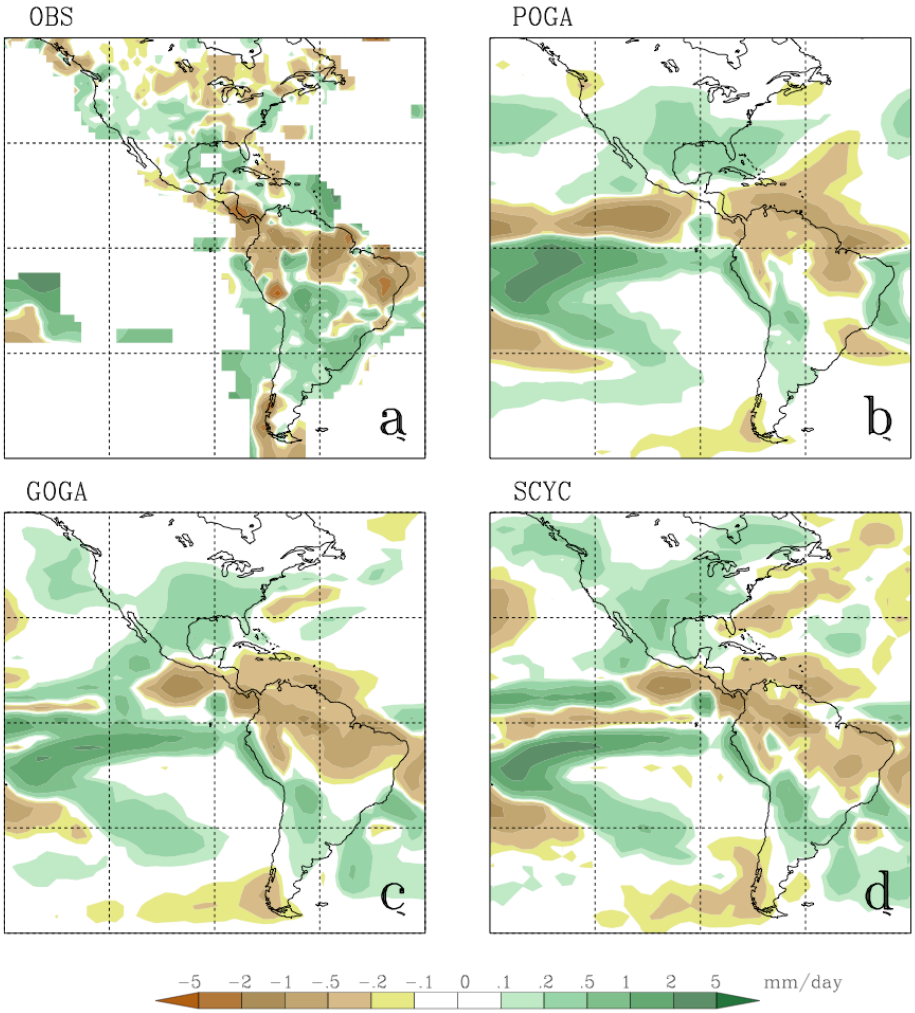
Herweijer, C., R. Seager and E. R. Cook, 2005: North American droughts of the mid to late Nineteenth Century: History, simulation and implications for Medieval drought. The Holocene, submitted.

Herweijer, C. and R. Seager, 2005: The hemispherically and zonally symmetric global footprint of persistent extratropical precipitation anomalies over the last 150 years. J. Climate, to be submitted June 2005.

Huang, H.P., R. Seager and Y. Kushnir, 2005: The 1976/77 precipitation shift across the Americas and the influence of tropical SST. Climate Dynamics, in press.

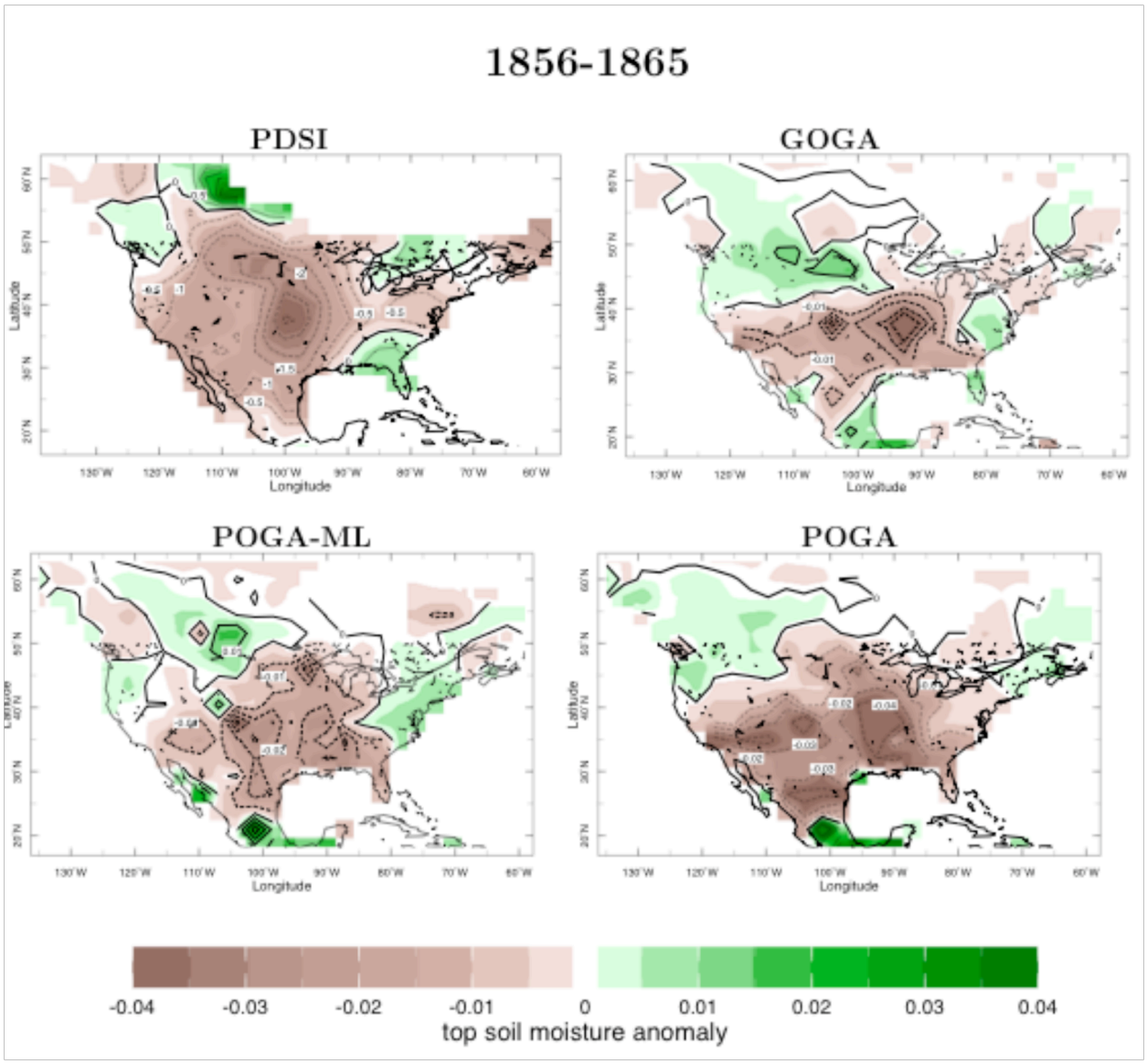
Ihara, C., Y. Kushnir, M. Cane, and V. de la Peña, 2005: Indian Summer Monsoon Rainfall and Its Link with ENSO and the Indian Ocean Dipole Mode. Int. J. Climatol., submitted.

Ting, M., and H. Wang, 2005: The role of the North American topography on the maintenance of the Great Plains summer low-level jet. J. Atmos. Sci., submitted.



The "post− minus pre−1976" difference in Jan−May precipitation, as measured by the difference between two time intervals: 1976-1978 and 1961-1976

Shown are: (a) Observation based on the CAMS dataset. (b) The GCM ensemble average of 16-runs forced with observed SST prescribed in the tropical Pacific and calculated using a variable-depth mixed layer everywhere else (POGA-ML experiment). (c) The GCM ensemble average of 48 runs with time varying SST prescribed over the entire global ocean (GOGA experiment). (d) The thirty-year average of the difference between a pair of the long integration of a GCM with global SST held fixed at their pre- and post 1976 shift states. Units are in mm/day with color scales indicated at bottom. White areas indicate insufficient data or very weak signals (within±0.1mm/day). The domain shown is 150°W−30°W and 60°S−60°N (Figure 2 from Huang et al, 2005). The GCM in all experiments is the NCAR CCM3 atmospheric model. The figure demonstrates that the model is capable of simulating many of the details of the change in precipitation over the Americas during the 1976 “climate shift”, including the wetting of North America after 1976. The results also show that the changes are not due to rectification effect of interannual SST variations but are linearly related to the change in the decadal means. The similarity between the POGA and GOGA ensemble results indicates the precipitation changes were forced from the tropical Pacific.



The 1856-1865 US drought ("Civil War drought") as seen in the Cook et al. tree ring based atlas of Palmer Drought Index (PDSI), and SST forced GCM ensembles (see explanation to acronyms in the previous figure; the POGA run is like the POGA-ML only with climatological SST over the world ocean outside the tropical Pacific).

THEME III: Applications Research

Project Title: **M. A. Program in Climate & Society**

Principal Investigator: Mark Cane
Affiliation: Lamont-Doherty Earth Observatory

NOAA Program Manager: Dr. Kenneth Mooney, Deputy Director, OGP, 301- 427- 2381, Kenneth.mooney@noaa.gov

Research Goals:

This is an educational program.

Education Goals:

The twelve-month M.A. Program in Climate and Society trains professionals and academics to understand and cope with the impacts of climate variability and climate change on society and the environment. This rigorous program emphasizes the problems of developing societies.

Research Progress:

The first group of 18 students to attend the M.A. Program in Climate and Society in Academic Year 2004-05 began the program in September 2004 and completed all requirements for the master's degree in August 2005. The degrees will be conferred in October 2005. The eighteen students came from a variety of countries and backgrounds, including mid-career professionals from Ethiopia and the United States, recent college graduates from the United States, and a variety of students from fields in policy, activism, and education from the United States, Cameroon, and Philippines.

Students completed a unique 12-month interdisciplinary curriculum especially designed and taught by researchers at the International Research Institute for Climate Prediction (IRI) at Columbia University. Through their intensive contact with these researchers, students gained appreciation for the interplay of climate variability, climate change, policy for development, risk, hazards, and natural and human impacts.

At the end of the program in August 2005, students expressed great satisfaction with twelve months of intensive learning, and prospects for job placement are excellent.

One student will start a PhD Program at the Rosenstiel School of Atmospheric and Marine Sciences, Univ. of Miami.
One student will serve as Climate Change Policy Coordinator at the British Embassy in Washington, D.C.
Two students will return to their careers in the public sector (health and meteorological services, respectively) in Ethiopia.
One student has accepted a position as Program Coordinator at Columbia's Global Roundtable on Climate Change (GROCC).
One student will remain at the International Research Institute for Climate Prediction (IRI) at Columbia University for a few months under the "Academic Training" provision of her exchange visitor student visa before returning to Philippines.
One student has been offered work with the UNDP on a consultancy basis upon return to his native Cameroon after the master's degree program.
One student has accepted a position as a teacher at an independent secondary school in Connecticut, where he will design his own integrated Earth Science Curriculum, using concepts he learned in the M.A. Program.

Highlights:

- Successful design and execution of a unique interdisciplinary curriculum that has not been carried out at the master's level at any other educational institution.

- Successful completion of the master's degree by all 18 graduate students in the 12-month timeframe; they will receive their degrees in October 2005.
- Summer internship and job placement at prestigious institutions and prominent names in the field of climate/society interactions (e.g., Pew Center, Environmental Defense, UNDP, CISA)

Societal Benefits:

Graduates of the M.A. Program in Climate and Society will form a group of uniquely qualified public and private sector professionals and researchers. The interdisciplinary curriculum challenges students to think in an integrated fashion about climate, climate impacts, and challenges to development from the very beginning. These graduates are able to address environmental and social phenomena from an integrated perspective that focuses on understanding multiple facets of a problem, from energy policy, energy demand, malaria epidemic mitigation, famine, drought, and flood early warning and mitigation, water resources management, environmental journalism, communication of climate variability and climate-related risks, and environmental secondary education.

The students' research has resulted in a number of societally useful products, including:

- A better prediction scheme for Ethiopian rainfall
- Integration of climate information into malaria control efforts in Ethiopia
- Better understanding of climate influences on locusts in the Sahel
- A curriculum on Climate and Society for secondary schools
- Improved agricultural data sets for south India
- Climate-based Reservoir analysis for New York City

CICAR / NOAA Funded Research Connections:

Research Partnerships and Collaborators:

Students in the M.A. Program in Climate and Society learned from and worked on research projects through the International Research Institute for Climate Prediction (IRI); The Earth Institute at Columbia University; the Earth Engineering Center at Columbia's School of Engineering and Applied Science (SEAS); and Columbia's Global Roundtable on Climate Change (GROCC), Columbia's NSF-funded Center for Research on Environmental Decisions (CRED).

Students who completed summer internships for academic credit worked at a variety of environmental and climate research organizations, including Environmental Defense; the Pew Center on Global Climate Change; NOAA-affiliated Carolinas Integrated Sciences & Assessments (CISA); United Nations Development Program (UNDP) Climate Change Management Office.

Awards/Honors:

Academic Year 2004-05, M.A. students were awarded in several ways.

Mr. Diriba Korecha Dadi of Ethiopia won a full scholarship from the Joint Japan / World Bank Scholarship Program to attend the program. Dadi is an early forecast warning team leader at the National Meteorological Services Agency of Ethiopia.

M.A. student Lauren Faber, a recent graduate of Stanford University, was one of two Columbia graduate students to win the "Student Energy Research Fellowship" from the Center for Energy and Marine Transportation and Public Policy at Columbia. This award usually goes to a public affairs or Engineering student, and it is rather unusual for the award to go to a student of the Graduate School of Arts and Sciences.

M.A. student Lauren Faber was chosen to attend the American Meteorological Society's (AMS) two-week Summer Policy Colloquium in Washington, D.C. This honor usually goes to PhD students.

M.A. Student Tara DePorte was awarded a travel grant to attend the SOLAS Summer School in Corsica, France, in August-September 2005. Admission and travel grant are usually awarded to PhD students.

Many students successfully competed for extremely competitive summer internships for academic credit, such as the Pew Center on Global Climate Change and the UNDP.

Education and Outreach:

Academic Outreach:

Postsecondary:

This is an educational program of the Graduate School of Arts and Sciences at Columbia University. The students actively participated in coursework for the Academic Year 2004-2005.

Research Advisor / Mentor:

Graduate: 18 Students

Professor Mark Cane is the formal Academic Advisor for these students and all 18 will receive the M.A. degree in October 2005. All students are either conducting formal job searches or have accepted offers. One student has accepted an offer of admission to a PhD program at the University of Miami.

Fellowship Programs / Internships:

M.A. student Lauren Faber, a recent graduate of Stanford University, was one of two Columbia graduate students to win the "Student Energy Research Fellowship" from the Center for Energy and Marine Transportation and Public Policy at Columbia.

Public Outreach:

Columbia University supports a recruitment campaign to attract new applicants and publicize the M.A. Program. Outreach efforts include the use of various print media including a brochure, posters, and newspaper advertisements. The University also maintains a Climate and Society web site.

Intranet / Internet:

http://www.columbia.edu/climatesociety

Educational Tools:

The *Master of Arts Program in Climate and Society* boasts an entirely unique curriculum taught by Columbia faculty and researchers at the International Research Institute for Climate Prediction (IRI) at Columbia University.

Personnel:

Eight (8) Graduate students are supported under this grant, all other personnel are supported by funds received from sources other than this grant:

Research Scientist:	7
Visiting Scientist:	31
Research Support Staff:	4
Administrative:	1
Graduate Student:	18

Students In the ***Masters of Arts Program in Climate and Society*** participate in unique interdisciplinary curriculum designed around climate and climate impacts, with particular attention paid to the developing world. These master's students receive personalized attention from some of the leading researchers in the field.

Photo credit:
Bruce Gilbert

Looking Forward

On September 28, 2005 CICAR is set to host a one-day symposium entitled "The Climate of the Last Millennium". The symposium agenda is consistent with our collaborative project with GFDL and will feature invited review talks addressing what we know about changes in global and regional climate during the last 1,000 years, the underlying physical mechanisms, and the relevance of these changes to society.

CICAR representatives will be present when the Lamont-Doherty Earth Observatory opens its doors to the public on Saturday, October 1, 2005 for an insider's look into the Earth's complex systems. As we did last year during this event, the Institute will host a display showcasing NOAA sponsored science on campus. We will also feature and distribute informational and promotional materials generously supplied by NOAA and developed by CICAR administration for classroom use.

In looking forward we are also planning to revisit our research, education, and outreach strategy, spelled in our original proposal to NOAA a little over two years ago. Our administrative framework provides us with a structure to conduct a live process of strategic planning. We conduct frequent meetings with LDEO Administration Office of Contracts and Grants to monitor the progress on grant submission and processing, to modify procedures or adopt new ones, and to communicate to the LDEO Division Administrators. By meeting twice a year or more (on need basis) we communicate with the CICAR Advisory Board that includes representatives from all Lamont Divisions and the different climate research disciplines. The Advisory Board assists the Director in reviewing and deciding operational and strategic matters. Similar regular communications are held between the CICAR Director and the Directors of LDEO and GFDL. At the end of this month (September 2005) CICAR will convene the first meeting of its (external) Executive Board, which includes representatives from other parts of Columbia University and from NOAA. We plan to convene the Board once a year to seek guidance and input relevant to our scientific and education agenda. With the help of this decision hierarchy we look forward to addressing the following issues and building on past planning and achievements:

- Broaden collaboration with NOAA:
  - Likely partners: NCEP/CPC; CDC; NCDC;
  - Discussion points: establishing a dialogue; identify areas for joint activities and resources; identify other NOAA partners.
- Broaden involvement of Columbia University units:
  - Particular emphasis: climate applications research
  - Likely partners: CIESEN, IRI, DEEE, Public Health, SIPA, CERC
  - Discussion points: identify areas of collaboration, means of communication, and resources.
- Strengthen outreach and education activities:
  - Strengthen CICAR links to CU & Barnard College. Develop links to secondary and post-secondary schools in the region.
  - Discussion points: Are there existing connections that CICAR can build on? What are the resources available to create an ongoing NOAA-CU education initiative with outreach to secondary and post-secondary institutions (emphasizing minority involvement)
- Develop ties to other regional research and education institutions:
  - Symposium on "Climate of the Last Millennium" as a springboard to a regional collaboration on this subject: LDEO, GFDL, CICS, WHOI, GISS, and Rutgers University.

With these plans in mind we will continue to advance our active participation in and contribution to the NOAA research and education agenda.

Appendix

CICAR Principal Investigators and Projects
July 1, 2004 to June 30, 2005

Table 1

Name	Title	Project	NOAA Goal	Task	Theme
Anderson, Robert	*Doherty Senior Scholar*	ARCHES: Paleo Sea-Ice Distributions	2	3	2
Bond, Gerard	*Doherty Senior Scholar*	ARCHES: High Resolution Investigations of Concentration and Petrologies of Ice-Rafted Grains in the Southern Ocean	2	3	2
Broecker, Wallace	*Newberry Professor*	ARCHES: Understanding Abrupt Change and the Glacial to Interglacial CO_2 Record	2	3	2
Cane, Mark	*Vetlesen Professor*	M. A. Program in Climate & Society	2	4	3
Cane, Mark	*Vetlesen Professor*	Dynamical Forecasting of ENSO: A Contribution to the IRI Network	2	3	1
Chen, Dake	*Doherty Senior Research Scientist*	Describing, Understanding and Predicting Oceanic Variations Associated with Tropical Atlantic Variability and The North Atlantic Oscillation	2	3	1
Cook, Edward	*Doherty Senior Scholar*	Collaborative Research: Development of a Blended Living Gridded Network of Drought Reconstructions of North America	2	3	2 (*3)
Denton, George	*LDEO Sub-grantee: Institute for Quaternary & Climate Studies, University of Maine*	ARCHES: Mountain Snowlines in the Southern Hemisphere	2	3	2
Gordon, Arnold	*Professor*	ARCHES: Modern Observations	2	3	2
Hayes, John	*LDEO Sub-grantee: Woods Hole Oceanographic Institution*	ARCHES: Accelerator Mass Spectrometric Analyses of RadioCarbon	2	3	2
Hemming, Sydney	*Associate Professor*	ARCHES: Constraining Changes in Winds, the Conveyor and Local Currents During Periods of Abrupt Climate Change	2	3	2

Name	Title	Project	NOAA Goal	Task	Theme
Kaplan, Alexey	*Doherty Research Scientist*	Multivariate Approach to Ensemble Reconstruction of Historical Marine Surface Winds from Ships and Satellites	2	3	2 (*3)
Kushnir, Yochanan	*Doherty Senior Research Scientist*	The Cooperative Institute for Climate Applications and Research - Administration	2	1	N/A
Lynch-Stieglitz, Jean	*Adjunct Research Scientist*	ARCHES: Patterns and Timing of Deglacial Climate Change in the Equatorial Pacific	2	3	2
Martinson, Douglas	*Doherty Senior Research Scientist*	ARCHES: Southern Ocean Modeling and Analysis	2	3	1
McGillis, Wade	*Doherty Research Scientist*	Atmosphere and Coastal Ocean CO_2 Measurement Platform - SABSOON	2	3	2
McGillis, Wade	*Doherty Research Scientist*	SOLAS OASIS Platform	2	3	2
Robertson, Andrew	*Research Scientist*	South Atlantic Ocean-Atmosphere Interaction	2	3	1
Schlosser, Peter	*Professor*	ARCHES: Tracer Observations of Deep Formation and Circulation in the Southern Ocean	2	3	2
Seager, Richard	*Doherty Senior Research Scientist*	Understanding Climate Change from the Medieval Warm Period to the Greenhouse Future	2	4	1
Seager, Richard	*Doherty Senior Research Scientist*	ARCHES: Mechanisms of Abrupt Climate Change	2	3	1
Smethie, William	*Doherty Senior Research Scientist*	ARCHES: Tracer Observations of Deep Formation and Circulation in the Southern Ocean	2	3	2
Ting, Mingfang	*Doherty Senior Research Scientist*	The Role of Orography on the North American Monsoon Onset and Interannual Variability	2	3	1
Visbeck, Martin	*Adjunct Senior Research Scientist*	The Role of Ocean Dynamics in Tropical Atlantic SST	2	3	1

*** Indicates sub-theme**

Table 2.
CICAR Funding Analysis by Goal, Task, and Theme:

Total: Projects Funded			**24**
BY: NOAA Goal # 2		24	
Task I	1		
Task II	0		
Task III	21		
Task IV	2		
		24	
CICAR Administration	1		
Theme I	8		
Theme II	14		
Theme III	1		
		24	

Table 3.
Lead Author Publication Table

	JI Lead Author			NOAA Lead Author			Other Lead Author		
	2002-2003	2003-2004	2004-2005	2002-2003	2003-2004	2004-2005	2002-2003	2003-2004	2004-2005
Lamont – Doherty Earth Observatory									
Peer Reviewed		4	36					4	30
Non Peer Reviewed	2	1					1		
University of Maine, Quaternary & Climate Studies									
Peer Reviewed			2						
Non Peer Reviewed									

Publications

The following lists represent research papers that were prepared and published with full or partial support of NOAA funding. These are papers that either saw print during the 2004/05 reporting period, are still in press, or have been submitted to scientific journals or publishers and are still under review.

Journal Articles

1. Andersen, C., G. Bond, A. Kuijjpers, P. Knutz, and S. Bjorck, S., 2005: Holocene climate variability at multidecadal time scales detected by sedimentological indicators in a shelf core NW off Iceland, *Marine Geology*, **214**, p. 323-338.

2. Biasutti, M., A. H. Sobel and Y. Kushnir, 2005: GCM precipitation biases in the tropical Atlantic. J. Climate, submitted.

3. Cane, M. A., 2005: The evolution of El Nino, past and future. Earth and Planetary Science Letters, 230, 227-240.

4. Cane, M. A., 2005: The evolution of El Nino, past and future. *Earth and Planetary Science Letters*, **230**(3-4): 227-240.

5. Chen, D., P. Xie, Y. Xue, P. Arkin and Z. Wang, 2005: Impact and uncertainty of interannual precipitation variability over the tropical oceans. *J. Geophys. Res.,* submitted.

6. Chiang, J. C. H., and A. Koutavas (2004), Climate Change: Tropical Flip-Flop Connections, Nature, 432, 684-685.

7. Clement, A. C., R. Seager and R. Murtugudde, 2005: On the existence of tropical warm pools. J. Climate, in press.

8. Clement, A.C. and B. Soden, 2005: The sensitivity of the tropical-mean radiation budget. J. Climate, in press.

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10. Cullather, R. et al., 2005: An assessment of IPCC coupled model simulations of the Antarctic climate, Clim. Dynamics, submitted.

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Table 4.

Personnel Information Table July 1, 2004 – June 30, 2005

The Cooperative Institute for Climate Applications and Research

Category	Number	H.S.	B.A.	B.S.	M.A.	M.S.	Ph.D.
Research Scientist	**5**						5
Postdoctoral Fellow	**2**						2
Research Support Staff	**8**				1	4	3
Administrative	**5**	1	0	3	0	1	0
TOTAL Support > 50%	**20**	1	0	3	1	5	10
Undergraduate	**0**	0	0				
Graduate	**11**		5	4		2	
Total Support < 50%	**45**						
@ GFDL	**0**						
Obtained NOAA Employment	**2**						2

Two (2) Postdoctoral Fellows received offers of employment from NOAA and commenced employment within the current reporting period:

1. Name: Qian "Scott" Song
   NOAA Agency / Lab: GFDL
   Date of Hire / Appointment: June 2004
   Title / Duties: Post-Doc
   Acceptance Date: June 2004
   Start Date: July 1, 2004

2. Name: Alicia Karspeck
   NOAA Agency / Lab: The National Center for Atmospheric Research (NCAR) Boulder, Co.
   Date of Hire / Appointment: December 31, 2004
   Title / Duties: Postdoctoral Research Fellow / Independent research
   Acceptance Date: April 15, 2004
   Start Date: December 31, 2004

Awards & Honors

Anderson was elected a Fellow of the AGU in 2005.

Anderson will receive the Huntsman Medal offered jointly by Dalhousie University and the Bedford Institute of Oceanography in September 2005.

Alex Piotrowski was selected for a student poster prize at the ICP8 meeting in Biarritz France Sept 2004

2004 American Geophysical Union Editor's Citation for Excellence in Refereeing for *Paleoceanography*, presented to Athanasios Koutavas

First Place Poster Competition, Paleoclimate Modeling Intercomparison Project-2 Workshop, Giens, France 2005, Title: "Tropical Pacific SST gradients during the LGM and links with the ITCZ", presented by Athanasios Koutavas.

Yuan, "The Impact of High Latitude Climate Modes on Antarctic Sea Ice" at CliC First Science Conference, Beijing, China, 11-15, April 2005 (chosen as Honorable Mention Poster).

Mr. Diriba Korecha Dadi of Ethiopia won a full scholarship from the Joint Japan / World Bank Scholarship Program to attend the M.A. in Climate & Society program. Dadi is an early forecast warning team leader at the National Meteorological Services Agency of Ethiopia.

M.A. student Lauren Faber, a recent graduate of Stanford University, was one of two Columbia graduate students to win the "Student Energy Research Fellowship" from the Center for Energy and Marine Transportation and Public Policy at Columbia. This award usually goes to a public affairs or Engineering student, and it is rather unusual for the award to go to a student of the Graduate School of Arts and Sciences. M.A. in Climate & Society program.

M.A. student Lauren Faber was chosen to attend the American Meteorological Society's (AMS) two-week Summer Policy Colloquium in Washington, D.C. This honor usually goes to PhD students. M.A. in Climate & Society program.

M.A. Student Tara DePorte was awarded a travel grant to attend the SOLAS Summer School in Corsica, France, in August-September 2005. Admission and travel grant are usually awarded to PhD students. M.A. in Climate & Society program.

Many students successfully competed for extremely competitive summer internships for academic credit, such as the Pew Center on Global Climate Change and the UNDP. M.A. in Climate & Society program.

CICAR Funding Analysis Charts

Chart 1.

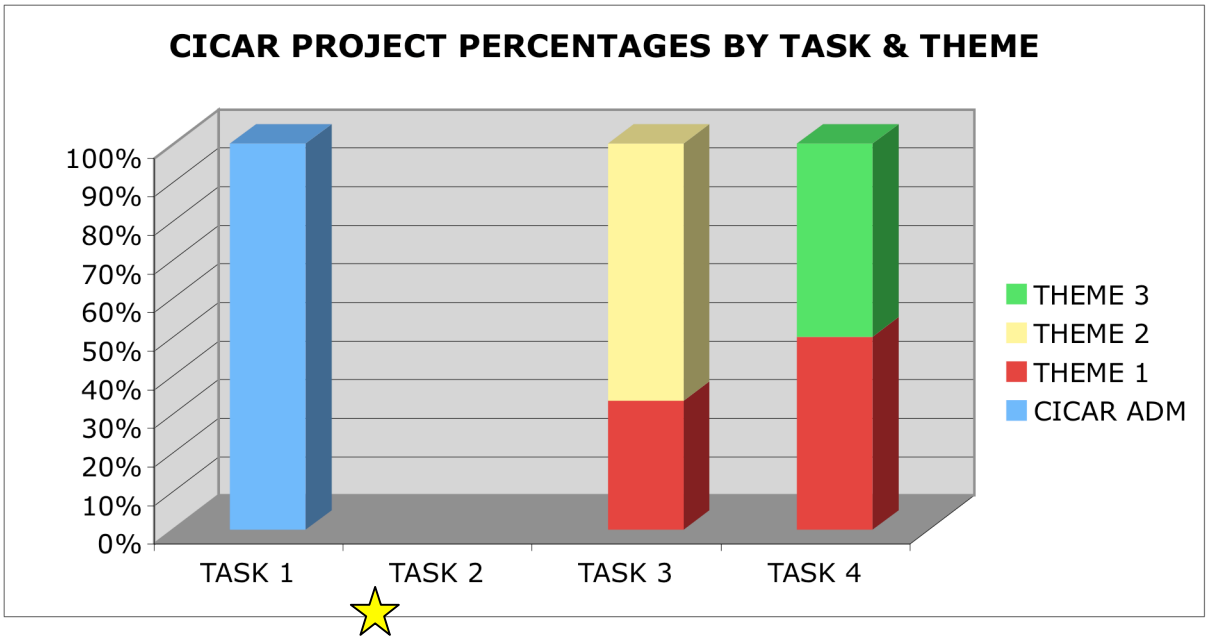
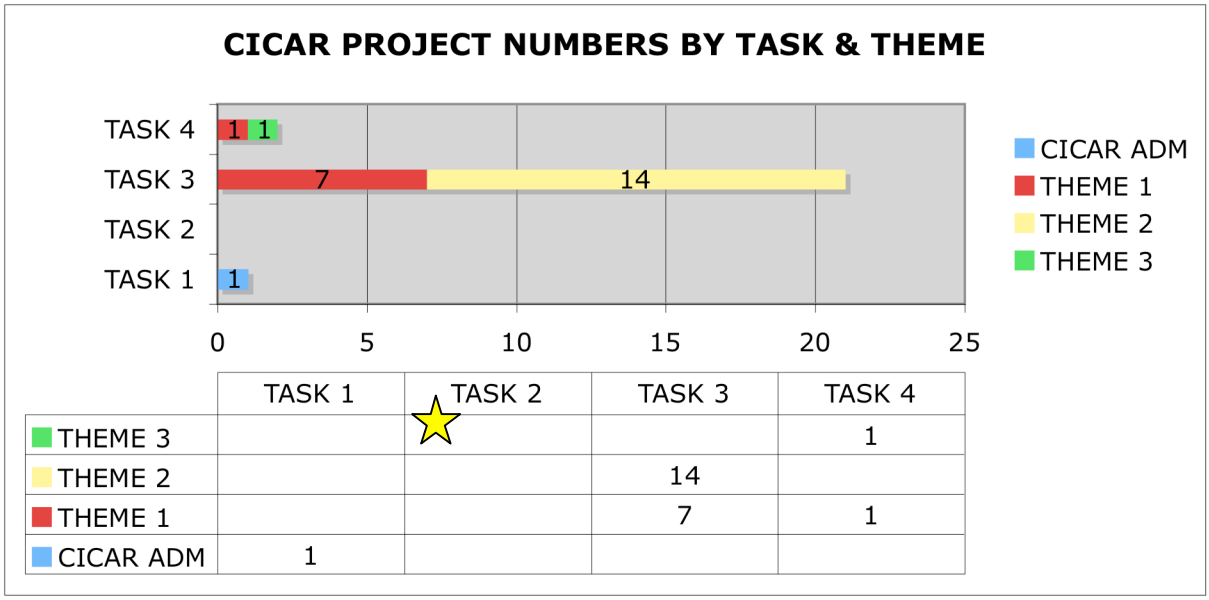


Chart 2.



	TASK 1	TASK 2	TASK 3	TASK 4
THEME 3				1
THEME 2			14	
THEME 1			7	1
CICAR ADM	1			

Task II provides for specialized support scientists that are employed by Columbia University (LDEO) but are located at the Geophysical Fluid Dynamics Laboratory (GFDL). To date, these slots have not been filled.